JOURNAL

of the

AMERICAN CONCRETE INSTITUTE

Published monthly except July and August by the
American Concrete Institute under the authority of the Board of Direction

EDITED BY THE SECRETARY

with the direction of the PUBLICATIONS COMMITTEE: W. A. SLATER, chairman; P. H. BATES, ARTHUR R. LORD, J. C. PEARSON, A. N. TALBOT, BENJAMIN WILK, HARVEY WHIPPLE, Secretary.

Papers: Original papers, furthering the objects of the society, are invited. They should be addressed to the Secretary, and their consideration by the Publications Committee will be facilitated if: (1) a brief but comprehensive outline or summary precedes or at least accompanies the completed paper; (2) manuscript and photographs are available in duplicate or triplicate; (3) original tracings or other drawings, from which copies are readily made, are available.

Effort will be made to advise authors promptly of decisions as to availability for publication. Acceptance of a paper does not imply the acquiescence of critics (whose advice is sought prior to acceptance) or of the Institute in opinions which it expresses nor the acceptance of data or practice which it records. Institute authority attaches only to standards adopted as provided in the By-Laws. The publication of a committee report implies merely the cooperative effort of an appointed group within the Institute. Acceptance of a paper or report for publication does not commit the Program committee in reference to the annual convention.

Subscription price $12.50 per year payable in advance. To members, $10.00 per year, included in the annual dues.

Bound volumes 1 to 22 of *Proceedings of the American Concrete Institute* (1905 to 1926)—$8.00 each so far as available; Volumes 23, 24, 25 (1927-1929) $10.00 each. To members $5.00 each. Volume 26 (1930) consisting of JOURNAL issues 1-8, November 1929-June 1930, bound without *News Letter* pages to non-members and non-subscribers, $12.50. Subscribers and members may obtain the volume (in addition to their monthly issues) at the end of the volume year at $6.00, so long as a limited supply of over-copies permits. Members may insure availability of not more than two copies of each volume at a special price when they place their orders in advance of the first JOURNAL issue of each volume.

Publication address: 2970 West Grand Boulevard, Detroit, Michigan. Entered at the Post Office at Detroit, Michigan, as mail of the second class under the provisions of the Act of March 3, 1879.

Copyrighted, 1930
American Concrete Institute.

AMERICAN CONCRETE INSTITUTE

Founded 1905; incorporated 1906 (National Association of Cement Users); charter amended 1913. (American Concrete Institute.)

BOARD OF DIRECTION

President

D. A. ABRAMS (Term expires Feb. 1931)

Vice-Presidents

S. C. HOLLISTER (Term expires Feb. 1931)
ARTHUR R. LORD (Term expires Feb. 1932)

Secretary and Treasurer

HARVEY WHIPPLE (Term expires Feb. 1931)

Directors:

First District—R. B. YOUNG (Term expires Feb. 1932)
Second District—CLOYD M. CHAPMAN (Term expires Feb. 1932)
Third District—J. C. PEARSON (Term expires Feb. 1931)
Fourth District—P. H. BATES (Term expires Feb. 1931)
Fifth District—F. R. McMILLAN (Term expires Feb. 1931)
Sixth District—RAYMOND E. DAVIS (Term expires Feb. 1932)

Past Presidents

RICHARD L. HUMPHREY Deceased (1905-14)
LEONARD C. WASON (1915-16)
WILLIAM K. HATT (1917-19)
*HENRY C. TURNER (1920-21)
*WILLIAM P. ANDERSON (1922-23)
*A. E. LINDAU (1924-25)
*M. M. UPSON (1926-27)
*E. D. BOYER (1928-29)

*The five latest, living past presidents are members of the Board.

VOL. 2—NO. 2 OCTOBER 1930 (*Proceedings Vol. 27*)

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

News Letter

PAPERS AND REPORTS IN THE MAKING

SUBJECT matter coming to the surface and representing possibilities of JOURNAL pages in the next few months (some at least included in the raw material that the Program Committee of the Institute is considering for the next convention) indicates wide range of appeal. "Coming to the surface" seems to be an appropriate expression in this instance since the prospective reports and papers involve a tremendous amount of "digging."

Capt. Helmer Swenholt's paper on the Bonne Carre Spillway, presented at the convention last February in its formative state has been completed and will be published shortly.

W. R. Johnson of Knoxville Power Co., Calderwood, Tenn., is writing about unusual features in the design, construction and actual making of concrete on the Calderwood tunnel job.

"Shrinkage Measurements of Concrete Masonry" discussed by W. D. M. Allan in a paper before the Institute last February and published in the JOURNAL for April, is still the subject of a continued investigation at the Portland Cement Association which will be reported in a sequel contribution.

A paper discussing slump and flow tests as pointing the way to a yard stick for workability is being prepared by Inge Lyse and W. R. Johnson.

Prof. S. C. Hollister has in preparation a paper on the effect on the properties of concrete of various methods of extracting excess water after placing.

An investigation of integral waterproofings at the U. S. Bureau of Standards, supplies P. H. Bates with material for a paper probably available soon.

A discussion which the Program Committee anticipates will require an entire convention session is being sponsored by Committee 801, Durability of Concrete, A. E. Lindau, Chairman, F. R. McMillan, Secretary.

Einar Christensen as author-chairman of Committee 203, Cinders as an

Aggregate for Concrete, has the preliminary draft of his report completed. In this he has endeavored to report the essence of available data.

Along similar lines, George E. McIntyre, Kansas City, as author-chairman of Committee 204, Burned Clay or Shale Aggregates, is working on a study of heat-treated clays as concrete aggregate.

Still in the field of light weight concrete, Frank A. Randall as author-chairman of Committee 406, Use of Light Weight Concrete in Buildings, is working on the report which will consider light weight concrete from a design standpoint, the economies of reduced loads, acoustical and insulating results, etc.

Committee 408, Recommended Practice for the use of Color in Concrete, W. D. M. Allan, chairman, is launched on a study with many ramifications. There will be an effort to produce a recommended practice for early presentation to the Institute that will lay the foundation for more detailed studies of particular uses of color.

"CATCHING UP" ON ABSTRACTS

IN THE current issue, as in the September JOURNAL, the Abstracts department has endeavored to "catch up" with abstracts material which accumulated in July and August when no JOURNAL was published. The abstracts pages which have been increased materially in number in the September and October JOURNALS will be more nearly normal in the November and subsequent issues of the present volume year.

IN CONSTANT REPAIR

(A Conversation with Dr. Sam'l Johnson)
Dr. Johnson: A man, Sir, should keep his Friendships in a state of Constant Repair.
The Author: And no less, Sir, his Information.

9. YESTERDAY

BY ARTHUR R. LORD

YESTERDAY was a very pleasant day. A pleasant sun, a pleasant cooling breeze. Pleasant reaches of concrete pavements extending, uncontested by traffic, one hundred fifty miles to Urbana. Agreeable companions, fellow engineers and friends of Chicago—Pete Hein, Ben Shapiro, Thumley. A moderate speed, sensibly maintained, clicked off the miles in rapid succession. And at the famed University of Illinois other old friends and one time companions in research. What more may one ask of one day?

And yet there was more given. More knowledge, old doubts resolved, new inspirations aroused. We travelled thus happily to witness tests of concrete columns. Not columns in the Institute's new research, part of which is also under way at Urbana now, but other columns that may well supplement that program. Incidentally Mr. Slater can no longer claim that the new tests exceed by one the number of all previous American and Canadian concrete column tests. These columns, twelve of them, had steel or cast iron cores inside the usual cage of spiral and vertical reinforcement. They failed at loads of 20,000 to 30,000 lb. per sq. in.—which should interest a designing engineer at least. And they

were even more slender than the usual building column!

These columns were made by a practical and successful contractor member of the Institute. The other engineers in my party, who witnessed the making also, tell me that I was spared considerable agony by not being present. Water was too freely used. Mr. Mensch is not yet a convert to the water-cement-ratio "delusion" fostered by Abrams or the void-cement ratio of Talbot and Richart. He likes his concrete workable and he made it that way by adding water instead of other things that I could mention—have mentioned in this column, in fact. And Messieurs Putnam and Richart were not altogether pleased with the specimens from the viewpoint of testing technique. Some of the ends of the columns were square and some were not. Mr. Mensch was not concerned—go ahead and test them. No capping was used to correct this difficulty. Two column cores were spliced at the mid-height. These columns slightly exceeded the strength of others in which the core was not spliced.

The highest ratio of metal core area to total column core area in this series was 59%, the lowest 38%. The 1928 Joint Code limits this percentage to 12. Mr. Mensch made these tests to convince the Code Committee of Engineers in Chicago that Institute Committee 501 was not happily inspired when it fixed on this figure twelve. He felt that it was a dull commonplace figure, merely picked at random. He seems to have established his point, for the higher percentages shouldered the load a bit more lustily than the lower. The steel and cast iron cores worked shoulder to shoulder, a Damon and Pythias affair, neither one willing to discredit the other.

It would seem that concrete columns, judged by these tests and many earlier ones which they confirm and supplement, are too big and lazy. It would seem that steel mills should roll solid steel cores of much larger diameter than are now promptly available, and that bar companies should carry them in stock. Solid cast iron cores as used in these tests are much preferable to (and cheaper than) hollow castings such as have been used, and are essential for columns with high percentages of core metal.

Yesterday was a profitable day in the Repair Department.

FINIS LA CONCRETE

BY HERBERT J. GILKEY*

FOR EIGHT MONTHS I have been expecting to hear that Vice-President Arthur R. Lord was turned completely inside out in an attempt to disgorge a question mark that got turned upside down. With such a flow of interrogation only the parent of a four-year-old can visualize the plight of his mother some 40 years ago.

For fourteen years I have known Mr. Lord for much knowledge and few words. Now I marvel at his unending stream of questions. Dr. Johnson never could have kept his "Universal" friendships, his "concrete" information his "Atlas" physique or his "quick setting" pantaloons in repair for ten minutes against such a barrage. And the missiles! Neither Dr. Johnson nor Noah Webster accepted them as fit for polite society. Try firing Celite? Bentonite? Barnsdal? Admix? Aquagel? Pumicite? Inertol? Gar Kem? Omicron? at your wife *just once* and

*Prof. Civil Engineering, University of Colorado, Boulder.

see what happens. And these are only part of the January installment!†

Is there something we don't know about concrete?

Not long since a member of the Institute who is also a professor of civil engineering approached the president of his University about funds for undertaking a little concrete research. Now this particular president is a scientist, a world-renowned scientist, in fact he is probably the most distinguished scientific president of any university in America or perhaps the world. It's a pity his name can't be told but that wouldn't be courteous to the president and it might "get the professor in dutch." The president was surprised that anyone should be curious about concrete.

"Hasn't everything been learned about that?"

If A. R. L. could only have stepped around the corner with his q-shooter at that instant.‡

But that isn't the end for after all the president was right. *Everything is known about that.*

Browsing over the "new-book shelf" in our library, a very interesting title caught my eye. "Materials Handbook—An Encyclopedia for Purchasing Agents, Engineers, Executives, and Foremen" by—(with a whole inch of claims to fame beneath his name) First Edition 1929; from one of the largest producers of engineering books in this country.

Because of a concrete complex it was natural that the book soon opened to page 108. There in one short paragraph was found all that anyone needs to know about concrete. A. R. L., D. A. A., F. R. Mc, and all the other 2729 members of the Institute (not to mention the college professor) have been working themselves into unnecessary frenzy.

Whenever anyone froths at the mouth, uses strange words, and spews pre-cast reinforced concrete question marks, tear out page 108 of the Materials Handbook and have the patient masticate it thoroughly before swallowing. Here is the corrective—from page 108.

CONCRETE—One of the most widely used construction materials. It is composed of portland cement, sand, and gravel or broken stone, in the proportions of 1 volume of cement to 2 of sand and 4 of stone, but these proportions are varied according to the strength, pureness, and other qualifications required. It is practically artificial rock. The sand used is usually roughly angular, and the stone sharply broken. Concrete to set in water is made with hydraulic lime instead of portland cement. Reinforced concrete is a combination of concrete with a steel internal structure generally composed of rods. It has great strength. Reinforced concrete is extensively used in buildings, bridges, telegraph poles, roads, and many other things.

Any recurring, mild attack can be headed off by chewing small bits of page 297. There it will be observed that portland cement "should be finely divided and contain about 75 per cent of *calcium carbonate*."

Vilhjalmur Stefansson has often remarked that he hoped some day to found a university dedicated to the "Unlearning of Things that have been Wrongly Learned."

Since nothing more remains to be learned about concrete, it is suggested that the American Concrete Institute be reorganized as an "Institute for Unlearning What We Thought We Knew About Concrete." Mr. Lord will be offered the chair of etymology and free

†"In Constant Repair—The Fifth Ingredient" by Arthur R. Lord, January Journal A. C. I., News Letter p. 11.

‡Anyway let it be said for the president that the financial assistance for concrete research was forthcoming.

scholarships will be provided for technical authors, editors and publishers because it is felt that their presence may add standing and prestige (to the football team).

THE NOMINATING COMMITTEE

BALLOTING for the Nominating Committee resulted in the choice of the following, each with the number of votes shown opposite his name:

A. E. Lindau, Chicago, 335.
Edward D. Boyer, New York, 329.
P. J. Freeman, Pittsburgh, 326.
F. H. Jackson, Washington, D. C., 320.
F. E. Richart, Urbana, Ill., 320.

Nominations are to be made for offices, the terms of whose present encumbents expire in February, 1931:

President, (1 year).
Vice-President (2 years).
Treasurer (1 year).
Director 3rd District (2 years)
Director 4th District (2 years)
Director 5th District (2 years)

Proceedings **Vol. 26 has been mailed to those who placed orders. Those who did not order should read announcement page 1 of September *News Letter*.**

A. C. I. MEMBERS

This new column of your News Letter *is concerned with* who *and* what—*emphasis on the former. That it may avoid promiscuousness the "who" element will be confined to members of, and the "what" element chiefly to matters affecting, actively or potentially, the interests of, this Institute. Will every member please consider himself on "the staff." The "changes of address" in every day's mail contain some germs of news but they are not enough. Your cooperation will be appreciated.*—EDITOR.

EDWARD L. ERICKSEN

Professor of Structural Engineering, Purdue University, has accepted the chair of Engineering Mechanics at the University of Michigan.

H. F. CLEMMER

formerly Technical Adviser for The Solvay Process Co., 40 Rector St., New York City, has moved to Washington, D. C., as Engineer of Tests and Materials, Engineer Dept., District of Columbia. Mr. Clemmer is chairman of the Institute's Committee 201, Aggregate Specifications, and a member of Committee 101, Survey of Current Research.

HALE SUTHERLAND

formerly Associate Professor of Structural Engineering, at the Massachusetts Institute of Technology, Cambridge, is now Professor of Civil Engineering and Head of the Department of Civil Engineering at Lehigh University, Bethlehem, Pa. John Wiley & Sons will soon bring out the first of two

volumes, *Introduction to Structural Theory and Design* by Sutherland and Bowman (H. L. Bowman, Professor of Civil Engineering, Drexel Institute, Philadelphia).

S. C. HOLLISTER

has been appointed to head the Structural Engineering department of the School of Civil Engineering, Purdue University. After attendance at the State College of Washington he was graduated from the University of Wisconsin and later gave instruction in Applied Mechanics at the University of Illinois. He is a member of the Tau Beta Pi, Sigma Tau, and Alpha Tau Omega and holder of the Wason medal for Research, for work reported in his 1928 American Concrete Institute paper, "The Design and Construction of a Skew Arch." He goes to Purdue from 18 years' experience in private practice in bridges and buildings, power development, sewage disposal and research in materials of construction. Professor Hollister was in charge of government design and construction of concrete ships during the World War; has contributed to the technical work of the American Concrete Institute, American Railway Engineering Association, American Society for Testing Materials, the Franklin Institute and the Society for the Promotion of Engineering Education. He has recently been engaged in problems arising from the welding of structural steel in buildings and bridges and brings to Purdue an active participation in the research work underlying this new art. Professor Hollister succeeds Professor Eriksen (see above).

Mr. Hollister is a member of the Board of Direction, American Concrete Institute, 1923 to 1928 as director for the third district; Vice-president since 1928; was chairman of the Institute's representation on the former Joint Committee on Specifications for Concrete and Reinforced Concrete in which he served as chairman of the sub-committee on Design; is again Chairman of A. C. I. representation on the newly organized Joint Committee; is Vice-chairman of the new committee and again heads the sub-committee on Design; has been otherwise active in administrative and technical work of the society.

H. FRANK MACHNER

met sudden death September 1, on the Rio-Sao Paulo highway, near Sao Jose dos Campos, east of Sao Paulo, Brazil, when the car he was driving met another in head-on collision. Mr. Machner, born in Pittsburgh, Pa., taken to Austria as a child, was educated in the Polytechnic School in Vienna. In Brazil he was resident engineer on the construction of the $1,500,000 building for the general offices of the Sao Paulo Tramway, Light & Power Co., a structure which does him credit. He also designed and built a number of concrete arch highway bridges in North Brazil and worked on railway construction.

NEW MEMBERS

TWENTY applicants for membership in August have been approved by the Board of Direction as follows:

ALBERT, ODD, 125 Prospect St., East Orange, N. J.

BALCOM, H. G., 10 East 47th St., New York, N. Y.

BLUE RIDGE TALC CO., INC., Henry, Va. (C. O. Kitson)

DONES, SAMUEL G., 584 Washington St., Dorchester, Mass.

ENGEL, W. L., 6407 Kenwood Ave., Chicago, Ill.

FAHN, FRANK, JR., 3006 Iona Terrace, Baltimore, Md.

FULLER COMPANY, Fuller Bldg., Catasauqua, Pa. (P. F. Stauffer)

HENRY, D. O., Spalding Bldg., Portland, Ore.

HUTCHINSON, HARDYE, JR., 1450 Harrison St., Oakland, Calif.

MCNULTY, JOSEPH A., 114 Liberty St., New York, N. Y.

MEPHAM & CO., GEO. S., 20th & Lynch Ave., St. Louis, Mo. (L. K. Ayers)

NAILCRETE CORP., THE, 105 West 40th St., New York, N. Y. (F. B. DeGress)

NICKEL PLATE SAND & GRAVEL CO., 610 Commerce Bldg., Erie, Pa. (H. F. Rath)

ORBECK, MARTIN J., c/o Holland, Ackerman & Holland, 106 E. Liberty St., Ann Arbor, Mich.

REICHARD-COULSTON, INC., 95 Madison Ave., New York, N. Y. (W. A. Kennedy)

RICKETSON MINERAL COLOR WORKS, 97 E. Wisconsin Ave., Milwaukee, Wis. (Frederick C. Bogk)

ROSSMAN, DR. JOSEPH, 1424 L. St. N. W., Washington, D. C.

TOMITA, M., c/o Materials Testing Laboratory, University of Illinois, Urbana, Ill.

WEBB, WALTER LORING, 1001 Chestnut St., Philadelphia, Pa.

WILEY, A. J., 620 Idaho Bldg., Boise, Idaho.

REINFORCED CONCRETE COLUMN TEST FUND

Cash previously acknowledged (See September JOURNAL)	$11,202.50
Material donations previously acknowledged	2,067.03
Services of assistants of Portland Cement Association previously acknowledged	6,000.00
	$19,269.53
Additional contributions since publication of Sept. JOURNAL:	
Kalman Steel Co., Chicago Reinforcing Bars and Steel column forms	115.00
Concrete Reinforcing Steel Institute, Chicago—cash	1,000.00
Services of Portland Cement Association assistants at University of Illinois and Lehigh University	2,000.00
	$22,384.53

Papers and Reports—In this Issue

Proceedings American Concrete Institute

Vol. 27—Pages 117-224

CONSTRUCTION OF MAIN CANAL LINING ON KITTITAS DIVISION, YAKIMA RECLAMATION PROJECT, WASHINGTON... 117
By ARTHUR RUETTGERS and A. A. WHITMORE

CONSTRUCTION AND DESIGN FEATURES OF HAYDITE CONCRETE 151
By F. E. RICHART and V. P. JENSEN

BLAST FURNACE SLAG AS CONCRETE AGGREGATE 183
Report of Committee 201, Aggregate Specifications

DISCUSSION OF: "REINFORCED CONCRETE COLUMN INVESTIGATION" 221

DISCUSSION OF: "SOME TESTS OF CONCRETE MASONRY CURED WITH HIGH PRESSURE STEAM" 222

Publication of discussion of the contributions in the following pages is on a time schedule. Please see inside cover pages

Construction of Main Canal Lining on Kittitas Division, Yakima Reclamation Project, Washington

BY ARTHUR RUETTGERS AND A. A. WHITMORE*

Construction work performed on the Kittitas Division of the Yakima Reclamation Project during the seasons of 1927 and 1928 included the placing, by contract, of about 55,000 cu. yds. of concrete in canal and tunnel lining, combination lining and flume sections, inverted siphons, culverts, turnouts, bridges, and miscellaneous canal structures. The greater portion of the concrete, about 52 per cent, was placed in 3-in. reinforced canal lining. A description of this work, which involved the successful development and use of some novel construction equipment and the application of the more modern methods for scientifically controlling the concreting operations, forms the main substance of this paper.

LOCATION, PURPOSE, AND GENERAL DESCRIPTION OF WORK

The Kittitas division of the Yakima project will, upon completion, provide facilities for the irrigation of about 72,000 acres of land in the higher reaches of the bowl-shaped Kittitas Valley, surrounding privately-irrigated bottom land centered at Ellensburg, Washington. The irrigation plan contemplates the diversion of 1,320 second feet of water from the Yakima River at the Easton dam, about 40 miles northwest of Ellensburg. The Main Canal, now completed, traverses the southern slope of the Yakima River Canyon for 26 miles to its entrance into the Kittitas Valley, where the canal divides—the north or larger branch (of 925 second feet capacity) crossing the river and skirting the

*Arthur Ruettgers, Engineer, Denver; A. A. Whitmore, Associate Engineer, Ellensburg, Wash., U. S. Bureau of Reclamation.

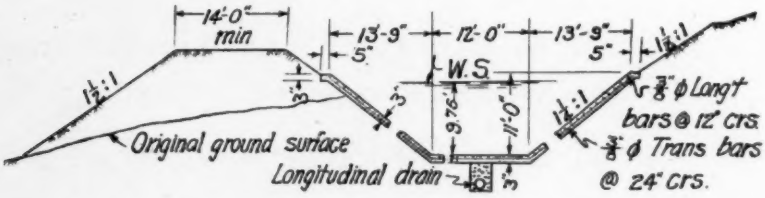


FIG. 1—TYPICAL SECTION CANAL LINING—NOT TO SCALE

FIG. 2—LOOKING UPSTREAM FROM STATION 1202 MAIN CANAL; TWO DRAGLINES EXCAVATING FOR LINED SECTION

northern and eastern rims of the valley, and the south branch (of 250 second feet capacity) following along the southern rim.

Stretches of the Main Canal, aggregating about half its entire length, were lined with 3-in. reinforced concrete to prevent excessive seepage losses in sand and gravel formations, to reduce the construction cost through heavy cuts, or to serve as a safeguard against expensive washouts on steep side-hill locations. Construction of the lined canal was performed under five separate

FIG. 3—TRIMMING AND LINING OPERATIONS; DRAGLINE EQUIPPED WITH CLAM SHELL BUCKET USED TO REMOVE EXCESS MATERIAL FROM TRIMMING OPERATIONS

FIG. 4—TEMPLATE USED IN TRIMMING OPERATIONS. LOOKING UPSTREAM FROM STATION 105 MAIN CANAL. OUTLET OF TUCKER CREEK SIPHON IN THE BACKGROUND

FIG. 5—APPARATUS USED BY DERBON CONSTRUCTION CO. FOR TRIMMING OPERATIONS ON DIVISION 3, MAIN CANAL. A SCREED BOARD PROVIDED WITH A STEEL CUTTING EDGE IS DRAWN DOWN THE SLOPE, THE ENDS OF THE CUTTING SCREED REST ON BOARDS SET TO GRADE OF CANAL SIDE SLOPE

contracts by four different contractors. A typical section of the canal is shown in Fig. 1.

WORK PRELIMINARY TO CONCRETING

Excavation. All rough excavation of the canal section was performed by draglines equipped with buckets of 1 to 2½ cu. yds. capacity. (Fig. 2). Smaller draglines, usually equipped with clam-shell buckets, were used to dispose of excess material removed in the trimming operations. (Fig. 3).

Trimming. The final trimming was generally done with the aid of a traveling template (Figs. 4 and 5), mounted on rollers, and consisting of two wooden trapezoidal-shaped frames so constructed and placed with respect to the canal center line and grade that a straight-edge moved along between the frames indicated the proper subgrade for the side slopes and canal bottom. The roller track was made of 3-in. by 6-in. plank

firmly embedded in the canal bottom, adjacent to the toe of each side slope. (Fig. 9). Removal of the high spots in the canal section and backfilling of the cavities were performed by hand methods. Cavities deeper than 6 in. were backfilled by placing moist material in thin horizontal layers and compacting with standard iron tampers, otherwise the compacting was done with flat steel shovels. Where the material was excessively sandy a thin layer was removed and replaced with clay to prevent ravelling of the surface. Further efforts to prevent ravelling of finished surface consisted in keeping the subgrade moist by sprinkling until the concrete was finally deposited. (Fig. 6).

The traveling template was also utilized in providing narrow berms at the tops of the side slopes. A ribbon of plank, placed on these berms, served as a second track for the operation of a movable scaffold from which the reinforcing steel on the side slopes was tied (Fig. 6) and subsequently to guide and support the concrete distributing platform and lining machines.

Drainage. Inasmuch as a 3-in. concrete lining in a canal section of the dimensions used offers little resistance to external pressure when the canal is empty, and as the region traversed is subject to a mean annual precipitation of some 20 ins., with the major portion occurring during the non-irrigation season, particular care was taken to provide adequate drainage for the lining. Longitudinal drains of 4-in. to 12-in. vitrified or concrete pipe, embedded in gravel, (Fig. 7) were laid beneath the floor of the lining in one or two lines, depending on the topography and ground water conditions encountered in excavating. Where the conditions appeared to require it, feeder or "finger" drains of gravel or tile, at right angles to and connecting with the longitudinal drains, were placed in the upper side slope of the lining. The importance of these finger drains, particularly at draws, was emphasized during the progress of the work by the failure of several panels on the upper slope through the action of hydrostatic pressure back of the lining. (Fig. 8). The early practice was to place the longitudinal drains along the center line of the canal but this was abandoned in favor of locating the drains near the toe of the upper slope, the latter location offering more

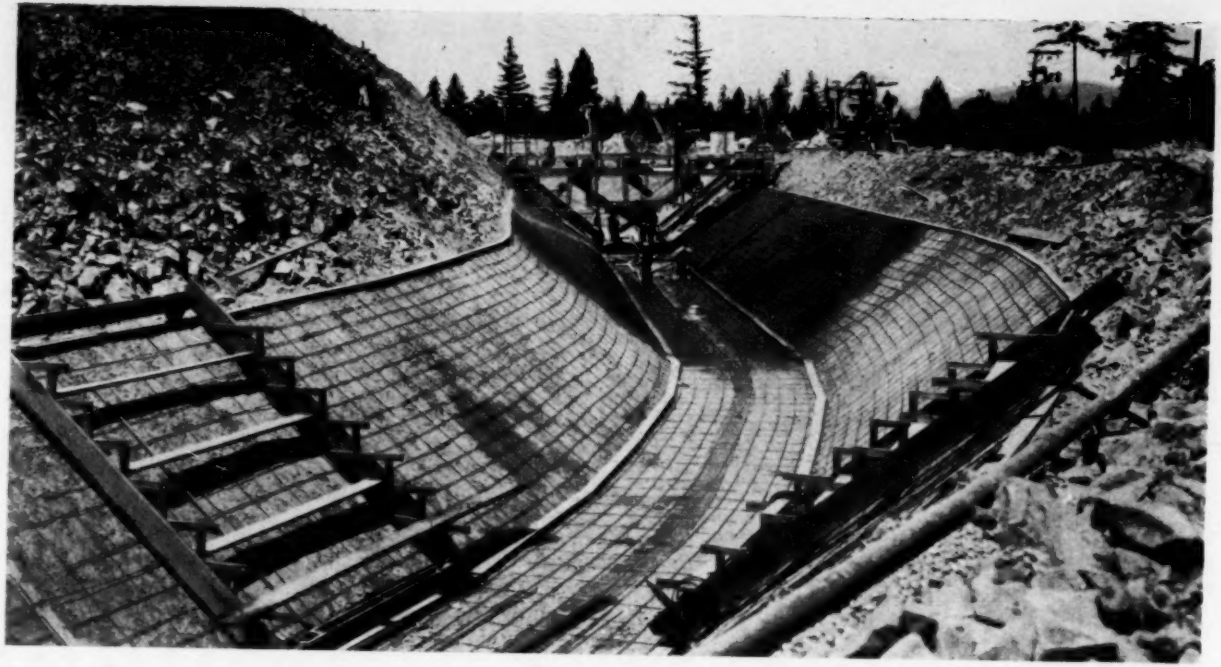


FIG. 6—LINING OPERATIONS—MAIN CANAL STATION 1094±. MOVABLE SCAFFOLD FOR TYING REINFORCING STEEL IN FOREGROUND. LINING MACHINE, CONCRETE DISTRIBUTING PLATFORM AND MIXER IN BACKGROUND, THE SUB-GRADE BEING WET DOWN PRIOR TO PLACING CONCRETE LINING

FIG. 7—CONSTRUCTING LONGITUDINAL DRAIN. TRIMMING "JUMBO" IN BACKGROUND. DRAGLINE EQUIPPED WITH CLAMSHELL BUCKET USED TO REMOVE EXCESS MATERIAL LEFT FROM TRIMMING OPERATIONS

direct connection with finger drains and better prospects for effective drainage in general. (Fig. 9). The longitudinal drains sloped in both directions to lateral or outlet drains, spaced 300 to 1,000 ft. or more apart and consisting of 6-in. to 12-in. pipe, with cemented joints, placed through or under the lower canal bank. (Fig. 10).

CONCRETING OPERATIONS

Requirements. The matter of devising the most suitable means for handling the concreting operations was not a simple one, as the character of the work and related specifications

FIG. 8—BREAK IN CANAL LINING CAUSED BY DEVELOPMENT OF HYDROSTATIC HEAD BEHIND THE LINING. STATION 90, MAIN CANAL

FIG. 9—GRAVEL "FINGER" OR SIDE SLOPE FEEDER DRAINS. (NOTE THE LONGITUDINAL DRAIN PLACED NEAR UPPER SIDE OF CANAL BASE.) ALSO NOTE RIBBONS AT THE TOP OF SIDE SLOPES AND ON BOTTOM OF CANAL ON WHICH THE CONCRETE LINING PLATFORM RUNS. LOOKING UPSTREAM FROM STATION 1224—MAIN CANAL

FIG. 10—DISCHARGE FROM LATERAL DRAINS—TWO 6-INCH PIPES DISCHARGING ABOUT ¾ SEC. FEET—STATION 140—MAIN CANAL

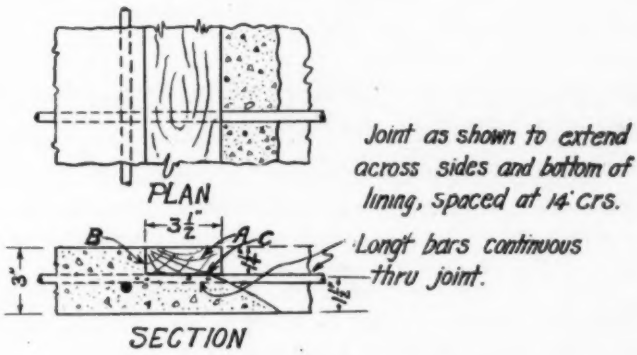
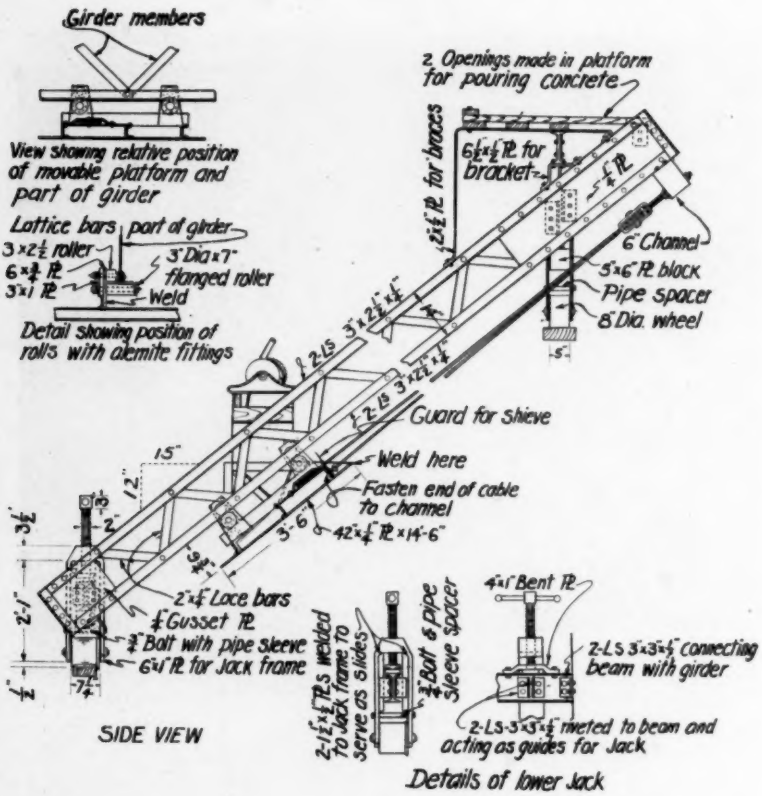


FIG. 11—DETAIL OF JOINT



required that account be taken of a variety of conditions, some of the principal ones being as follows:

(a) The size of the lined section, steepness of side slopes, small thickness of concrete, and difficulty of centering the reinforcing steel in the thin concrete slabs were not favorable for the adoption of the customary method of hand placement of the concrete.

(b) The top of the lower bank (of 14 ft. minimum width), which as a rule furnished the only means of direct access to the work, provided only a limited space for the storage of materials and the accommodation of operating equipment and crews.

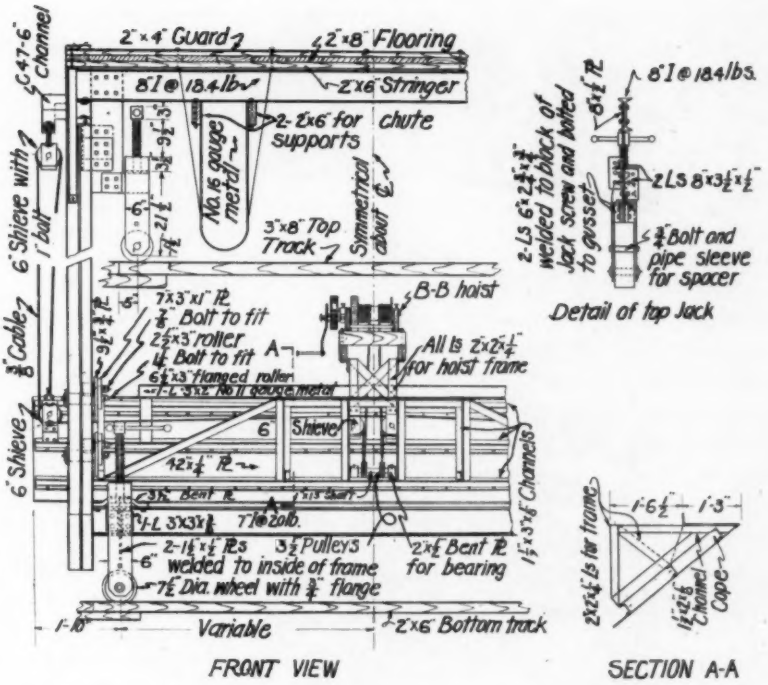


FIG. 12—MOVABLE FORM FOR PLACING CONCRETE LINING

(c) The distance over which the work was spread, and the necessity for completion within the allotted time, demanded mobility of all operating equipment. Simultaneous prosecution of concreting operations in several locations involved duplication of equipment and organization.

(d) The specifications required that the lining be placed monolithically in short panel sections and given a steel trowel finish. A special transverse joint (Fig. 11) later abandoned and replaced by a plain butt joint as hereinafter discussed was required at panel ends. Longitudinal joints (parallel to the axis of the canal) were not permitted.

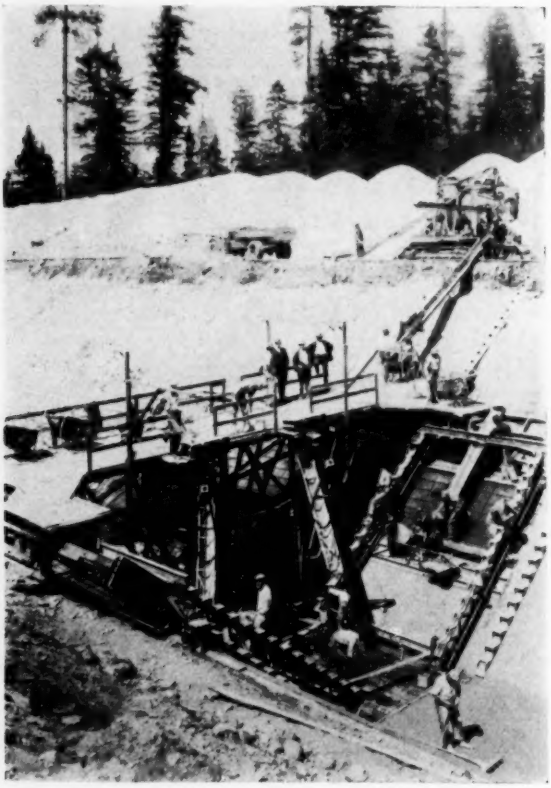


FIG. 13—ORIGINAL LINING MACHINE AND CONCRETE DISTRIBUTING PLATFORM DEVELOPED BY GENERAL CONSTRUCTION CO., CONTRACTOR FOR DIVISIONS 1 AND 2 MAIN CANAL. NOTE TRUCK ABOUT TO BACK UP AND DISCHARGE CEMENT AND AGGREGATES INTO HOPPER OF THE CATERPILLAR TRACTION PAVING MIXER. EACH TRUCK HANDLED 3 BATCHES OF DRY MATERIALS

(e) Neighboring creeks and the Yakima River furnished the only adequate and reliable sources of water.

(f) The bid prices were such that efficiency of operation and exercise of the strictest economy were essential for the realization of a profit.

The extent to which the first contractor succeeded in adapting his concreting operations to the particular requirements of the job, in lining approximately 2½ miles of Main Canal in 1927, is evidenced by the fact that all three of the other contractors who engaged in lining operations in 1928 employed methods and equipment embodying the same general principles, insofar as the handling and placing of concrete is concerned, as those which characterised the 1927 work.

Steel plate lining machine. Of particular interest is the novel machine designed and perfected by the forces of the General Construction Co. for lining the side slopes. (Fig. 12). It consists of a movable steel plate 14 ft. 6 in. long (the customary panel length being 14 ft.) and 3 ft. 6 in. wide, supported by and operating under two parallel fabricated steel girders with roller ends. (Figs. 13 and 14). An operating platform about 18 in. wide attached to the upper edge of the steel plate received the concrete and accommodated several workmen, in addition to carrying the winch by means of which the plate was made to travel upward along the canal slope and compact the concrete as it was spaded into the space back of the upper portion of the plate. A screw jack at each roller for raising or lowering the girders permitted adjustment of the plate to the required slope angle and thickness of concrete. The simultaneous use of two of these machines, one on each side slope, not only fulfilled the requirement for monolithic construction of panel units (the floor section being placed by hand immediately following completion of the slope sections) but also introduced an element of competition between the individual working crews which had a noticeable effect in speeding up the work.

Transporting and placing concrete. Wheel buggies were generally used to transport the concrete from the mixer, on the lower bank, to the canal section, where each batch was directed to its desired position on the side slope or bottom with the aid of a distributing platform mounted on rollers and equipped with a series of flexible chutes or spouts. The ribbons of plank track in the canal bottom and at the top of the lined slopes also served as screeds and, in the latter case, as outside forms for the 5-in. concrete berms.

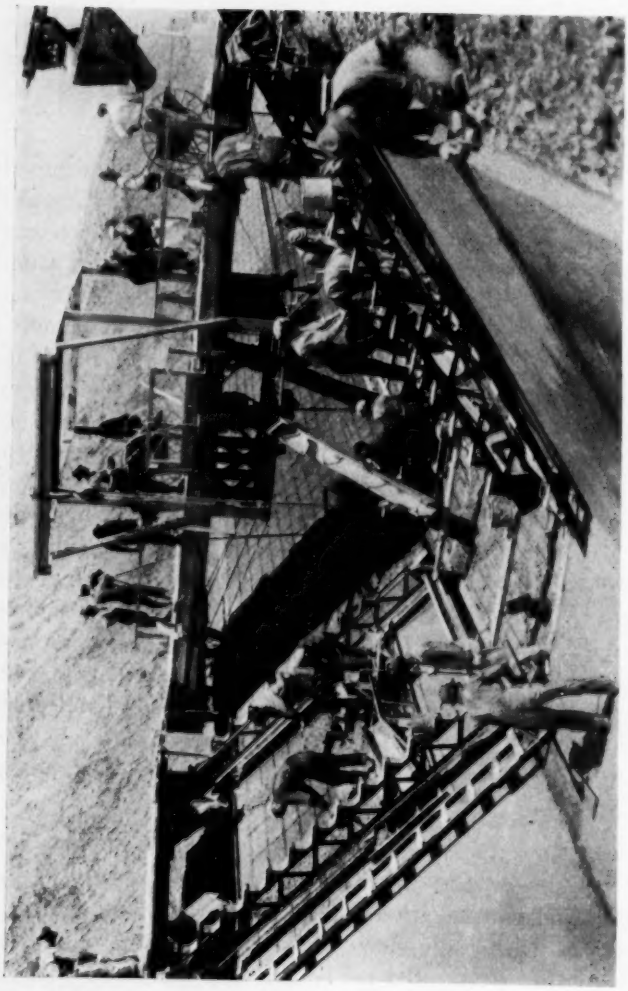


FIG. 14—LINING MACHINE SHOWING MOVABLE STEEL PLATE TRAVELING UP SIDE SLOPE. LINING IN PRECEDING PANEL BEING FINISHED AND CONCRETE BEING PLACED IN LOWER 3½ FEET OF SIDE SLOPES FOR SUCCEEDING PANEL. NOTCHED SCREED BOARD ON SIDE SLOPE UNDER "JUMBO"

About 10 complete panel units (equivalent to 140 linear feet of lining) constituted the average pour for one working shift of 8 hours, the record for a shift being 14 panels or 196 ft. of lined canal. The reinforcing steel was kept above the subgrade by inserting small pre-cast cement mortar blocks underneath the bars at various points as conditions required. Experience proved that the most practicable procedure for pouring the lower 3½ feet of slope lining was to shovel the concrete directly on to the slope (Fig. 14) and, after striking it off roughly, to lower the steel plate to position and rap it with a bar in order to bring the fine material into contact with the plate. Upon completion of this operation, the plate was started on its upward course, its movement keeping pace with the addition of concrete from the platform by the spaders. The action of the moving steel plate, with proper spading, correct concrete consistency and other related factors under control, resulted in a true surface and a reasonably good finish. The finish was perfected by going over the entire surface lightly with a long-handled steel trowel. Any defects appearing on the surface, due to insufficient mortar or spading, were remedied by adding the amount of concrete or mortar needed and trowelling over. Mortar was also used to provide fillets at the intersections of the floor and side slopes. The floor, as previously indicated, was placed by the usual hand methods, one of the last operations being to remove the plank track or screeds and fill in the grooves with tamped concrete after thoroughly cleaning the grooves (Fig. 14).

Other types of lining machines. Photographs reproduced in Figs. 15 and 16 show types of lining apparatus in which the general principles of the movable plate lining machine and distributing platform were combined in a single unit. These forms of apparatus involved a smaller plant investment and were devised by two of the contractors whose lining operations were less extensive. As seen from the pictures, the movable steel plate in the original slope lining machine was replaced by a metal-lined plank strike-off board, with operating platform, which, instead of being rigidly held down at its ends, simply

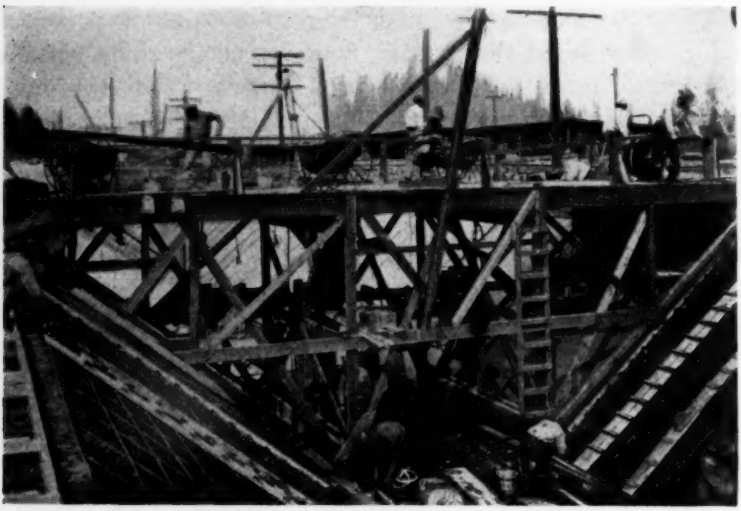


FIG. 15—COMBINED DISTRIBUTING PLATFORM AND MOVABLE STRIKE-OFF BOARD TYPE OF APPARATUS EMPLOYED BY C. F. GRAFF, CONTRACTOR FOR CONSTRUCTION OF EASTON DAM AND UPPER HALF-MILE OF KITTITAS MAIN CANAL

rode on two plank screeds spaced a panel-length apart and under the distributing platform, or "jumbo," as it was called.

In comparison with the steel plate lining machine, the spading board was less effective in compacting the concrete and drawing mortar for finishing to the surface, consequently more hand-finishing and a greater use of mortar was required. This feature of the spading board type of apparatus, coupled with its lack of headroom, greater dependence on a definite consistency of concrete for satisfactory operation, and other characteristic features tended to reduce the speed of concrete placement below that obtained by the use of the more expensive type of equipment, although it is believed that the quality of the lining secured was considerably better, and the cost to the contractor less, than would have resulted under the ordinary methods of hand placement.

Concrete materials. The materials entering into the lining construction, including sand and gravel shipped from Puget

FIG. 16—COMBINED DISTRIBUTING PLATFORM AND MOVABLE STRIKE-OFF BOARD EMPLOYED BY S. H. NEWELL & CO., CONTRACTOR FOR CONSTRUCTION OF DIVISION 2 (SCHEDULE 2), MAIN CANAL. CONTRACTOR STOCK PILED THE CEMENT AND AGGREGATES ON THE CANAL OPERATING ROAD

Sound, cement, diatomaceous earth admixture, reinforcing steel, and drainpipe were received by the contractors at the most convenient railroad points and hauled by them in motor trucks to the work. As a rule, the aggregates were dumped into stock piles, from elevated spur tracks provided by the contractors at the railroad delivery points, and loaded into trucks by mechanical loaders, or elevated to storage bins of central proportioning or mixing plants.

Concrete mixing. Concrete for the first half-mile of lining on the Main Canal was mixed at a stationary mixing plant (constructed primarily for the production of concrete for the Easton diversion dam) and hauled to the scene of lining operations in narrow-gage cars drawn by dinkey locomotives. With this one exception, all concrete placed in Main Canal lining was mixed in portable mixers which traveled the canal bank along with the concrete placing equipment. Modern paving mixers with cater-

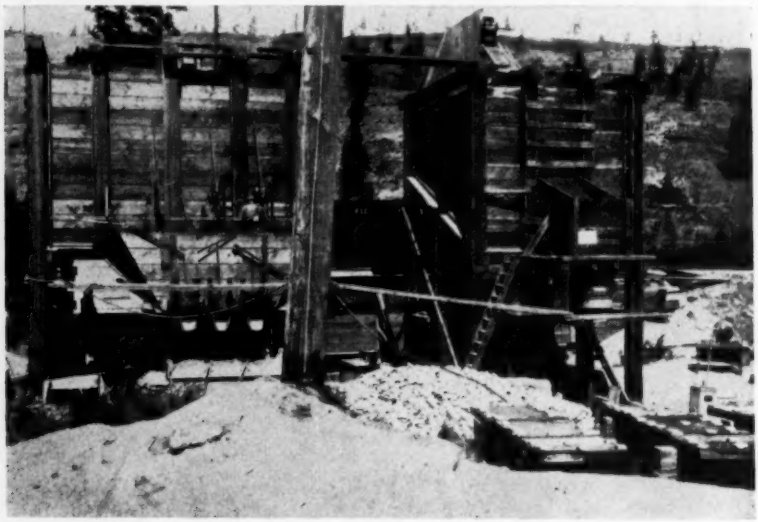


FIG. 17—DERBON CONSTRUCTION COMPANY'S SAND AND GRAVEL BUNKERS AT DERBON'S SPUR ON THE CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC RAILROAD ABOUT 1½ MILES WEST OF HORLICK

pillar traction were employed on some of the more recent work. (Fig. 13).

On two of the contracts the mixer was fed from stock piles of materials on the top of the bank, supplemented, where necessary, by direct motor truck deliveries from the main sources of material supply. On the remaining two contracts, the contractors established central proportioning plants at the railroad delivery points (Fig. 17) where the requisite aggregates, cement and admixture for a mixer batch were measured out and loaded into trucks with bodies specially constructed to handle three batches of the dry materials and, upon arrival at the mixer, to unload the batches separately into the charging hopper.

Water problems. The necessity for almost constant sprinkling of the subgrade from the time of final trimming until the concrete was laid, the use of water for mixing concrete and supplying camp needs, and the specification requirement for keeping the freshly placed concrete continuously damp for a minimum period

of 14 days created a heavy and steady demand for water. This demand was met, on four of the contracts, by piping from neighboring creeks or the Yakima river, usually with the aid of pumps, and, on certain sections of the work, by diverting the creek flow into completed portions of the lined canal and impounding it behind a small earth dike in the canal section. On the fifth and largest contract, an adequate creek flow was not available, and water for all purposes except curing was obtained by pumping from the Yakima river, through approximately 600 linear feet of 3-in. pipe and against a head of about 350 ft. to an elevated storage tank adjacent to the canal, whence it was pumped through smaller pipe of varying lengths to the particular locations required.

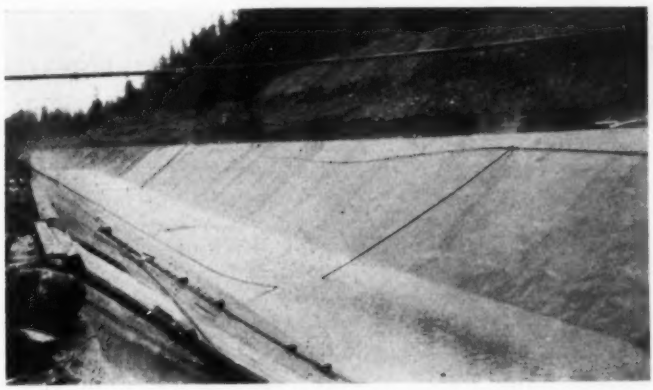


FIG. 18—CURING CANAL LINING BY WATER METHOD, USING BABB SPRINKLERS. BURLAP COVERING THE GREEN CONCRETE IS SHOWN IN THE BACKGROUND. STATION 103, MAIN CANAL

Concrete curing. Curing of the concrete by the water method was effectively accomplished by the use of Babb sprinklers (Fig. 18) at short intervals along two lines of pipe paralleling the canal center line—one on each side slope. Operation of the sprinklers was continuous for 14 days after the date of pouring, except for short night periods in certain instances. The lining was completely covered with a layer of burlap during the first seven days of curing, which served principally to protect the green concrete

FIG. 19—COMPLETED CANAL LINING. CURED BY HUNT PROCESS PAINT METHOD. PAINT IS SPRAYED ON IMMEDIATELY FOLLOWING THE FINISHING OPERATIONS

from the direct rays of the sun and distribute the applied moisture more uniformly.

A substitute for the water sprinkling method was employed in curing the lining in the last 6 miles of the Main Canal. The method used (Hunt Process), which was based on the principle of conserving the original mixing water for cement hydration, consisted in coating the exposed surfaces of the fresh concrete with a special asphaltic compound. The material was applied with a spraying machine (Fig. 19), immediately following the finishing operation.

Panel joints. Considerable trouble was experienced, during the earlier lining operations, in obtaining a satisfactory transverse construction joint between adjacent panel units. Details of the type of joint originally contemplated, and employed on other projects for lining of 4-in. or greater thickness, are shown in Fig. 11. The theory of the joint is that when the plank form A is removed from the partially hardened concrete (shown in

section) and fresh concrete is added, a good bond should develop with the irregular shaped tongue C, but the formed vertical surface B should bond very imperfectly and act as a plane of weakness to induce a crack. This result was not realized in practice, the cracks frequently taking a zig-zag course within the limits of the tongue, or a fairly regular path along a plane other than the one intended. The small thickness of the lining, the difficulty of obtaining the vertical surface and holding it after removal of the plank, and the apparent impracticability of securing a substantial tongue of concrete, are some of the reasons attributed for failure to produce a satisfactory joint of the type described. Various attempts were made to improve the joint. One was to leave the plank in place until the second pouring was completed and then fill in the groove, but this resulted in the formation of cracks along both edges. The best results were in using end plank or screeds of the full lining thickness and notched to accommodate the interfering longitudinal reinforcing bars (Fig. 15), thus eliminating the troublesome tongue of concrete and producing a plain butt joint. With the introduction of the butt type of joint, the top surface of the concrete at the joint was penetrated to a depth of about ¾-in., with a special tool similar to a sidewalk jointer, while the concrete was plastic, and the operation repeated after the concrete had stiffened. Cutting the joint was early discontinued, upon discovering that it was not required to insure the development of the crack at the joint. Use of the cutting tool, however, produced an excellent joint in that rounded shoulders were formed each side of the joint which do not spall under slight movement of lining resulting from temperature changes.

Transverse cracks. The lined section and construction joint were designed with the view of controlling the inevitable development of transverse cracks by inducing their occurrence at short regular intervals and along straight sightly lines. That this control was not fully realized with the perfection of the construction joint was evidenced by the appearance of additional intermediate transverse cracks within several days to six weeks after the concrete was placed. A survey of side-slope cracks along selected stretches of completed lining showed that the number of

intermediate cracks averaged 0.8 per 14-ft. panel for the water-cured lining and 1.3 for that cured with the asphalt coating. In other words, taking account of the regular construction joint cracks, the transverse cracks occurred at average intervals of 8 ft. and 6 ft. for the water-cured and asphalt-treated lining respectively—indicating that the amount of longitudinal reinforcing steel used might have been in excess of that required to restrict the contraction cracks to the 14-ft. spacing, under the particular conditions prevailing. Three principal reasons advanced for the increased number of intermediate cracks in the asphalt-treated lining (which increase was more marked on the north or sunny slope) are (1) the apparent greater surface drying through evaporation, (2) the more rapid setting-up of the concrete, permitting less adjustment between the concrete and reinforcing steel during the setting period, and (3) the probable greater daily range of temperature variations in the concrete, due to the black color of the surface coating.

Another significant feature revealed by the survey was that the first panel placed each day exhibited a tendency to develop from 1½ to 3 times as many intermediate cracks as the panels placed subsequently. Evidence obtained from an investigation of the possible causes of this phenomenon indicated quite conclusively that the restrained condition of the longitudinal steel in the first panel, by virtue of its embedment in the hardened concrete of the previous day's pour, was chiefly responsible for the excessive cracking tendency—the theory being that the rigid steel immediately adjacent to the hardened concrete offered greater opposition to the contraction forces in the new concrete, and consequently forced cracks at closer intervals.

CONCRETE MIXES, TESTS, AND CONTROL METHODS

Need for control. The liberal appropriations available and in prospect at the time construction of the canal and distribution systems of the Kittitas division was inaugurated offered favorable prospects for the prosecution of work on a rather large scale. It was early recognized that the production of uniform concrete of the best quality for the money was dependent upon a wise choice of aggregates and the development of a carefully prepared plan of procedure for concrete design, inspection and control.

The vital importance of securing quality concrete, as well as the justification for a reasonable amount of investigational and directional work leading to this end, became manifest when it was realized that estimated expenditures for the production of concrete for canal lining and structures represented approximately 50 per cent of the total proposed construction investment of $9,000,000.

Investigation of aggregates and concrete mix. Attention was first directed to the selection of suitable aggregates. This involved the preliminary testing, by the Bureau of Standards, of numerous samples of materials taken from local deposits, followed by an exhaustive test of further samples from the one local deposit which promised to be satisfactory. The latter test was conducted at a laboratory which had been established at the project office at Ellensburg and equipped to make the customary physical analyses, mortar briquette tests, and the 6 x 12-in. standard cylinder compression tests. Additional apparatus was subsequently installed for making impermeability tests of concrete discs 12 in. in diameter and 4 in. thick under water pressure. Before completion of the tests the aggregates exhibited some questionable characteristics and decision was finally reached to use a high quality sand and gravel from the Puget Sound region.

The specific aggregates for use having been selected, an extensive series of laboratory tests was carried on to determine the gradings and maximum sizes of aggregates best suited to meeting the various concrete requirements, to develop water-cement ratio strength control curves for the range of mixes contemplated, to establish the water-pressure-resisting properties of the different mixes, and to acquire other information of value such as the relation between strength, density of concrete, and density of dry mixed aggregates for various gravel to sand ratios, the effects of varying periods and kinds of curing, the resistance of concrete to weathering, and last but not least, the economic relationships. Standard specifications were followed in all laboratory procedure, except where such specifications were not available, as in the case of the impermeability tests. In practically all cases the laboratory test specimens were made with 2-in. and 6-in. slump concrete, this being the range of consistencies permitted by the construc-

tion specifications. The gravel to sand ratios used in the mixes first designed were based on the recommendations of Duff A. Abrams. These were modified somewhat after thorough trial in the field, for it was found that an increase in the proportion of sand, especially in the richer mixes, resulted in marked improvement in workability and concrete placement, without any appreciable sacrifice of strength or other desirable properties.

Control methods. One of the factors instrumental in unifying field concreting practice was a pocket-size loose-leaf booklet of "Instructions for Concrete Inspection and Control" which was prepared and blueprinted locally to serve as an auxiliary guide in the application and interpretation of the contract specifications and was placed in the hands of each concrete inspector and other employee directly connected with the work. Chapters in the booklet were devoted to responsibilities and general duties of the inspector, inspection of materials, distribution of splices in longitudinal reinforcing bars, forms and their removal, methods and periods of curing, mixing and placing of concrete, making the slump test, measuring concrete materials, determination of moisture in sand or gravel, field calculations for converting designed mix to field mix, making and storing 6 x 12 in. test cylinders, sampling aggregates and making sieve analyses, and effects of proper and improper curing of concrete. Tables were also included giving bulking allowances for moist sand (for use in volumetric proportioning), designed mixes and their uses, batch weights (including moisture) per sack of cement for each approved mix, surface moisture in sand and gravel per sack of cement, relation between dry rodded and dry loose mixes, and other miscellaneous data for reducing field computations to the minimum. The latest revision of "Concrete Mixes—and Their Uses" is given in Table 1.

While the booklet of instructions served as a vehicle for arousing the inspector's interest, enlarging his knowledge of concrete, and supplying him with a set of working rules and tables, it could not be expected to maintain that spirit of alertness and constant attention to details so essential to the control of the numerous operations involved in the making of good concrete—especially when the work was progressing at top speed. In other

TABLE 1—CONCRETE MIXES AND THEIR USES

Mix (Dry Rodded)	Size of Gravel Inches	Admixture Per Cent	Approximate Slump Inches	Approximate W/C Ratio	Sacks of Cement per Cu. Yd.*	Work in Which Used
1:1.6:2.4	½	0	5–6	.70	7.11	Lock joint pipe.
1:1.7:2.8	1¼	0	6	.67	6.55	Siphon barrels (over 100-feet head).
1:2.0:3.25	1¼	1½	6	.81	5.75	Siphon barrels (under 100-ft. head) and siphon transitions.
1:2.4:3.6	1¼	3	2	.87	5.03	Canal lining (unformed).
1:2.4:3.6	1¼	3	4–6	.93	5.02	Tunnel lining, canal lining (formed), part of dam where 3-in. aggregate is not suitable, and ordinary thin-walled structures
1:2.75:6.25	3	3	2–3	1.10	3.42	Interior of main body of dam.
1½:2.75:6.25	3	3	3–5	.80	4.96	3-ft. exterior of main body of dam.

NOTE: Sacks of cement per cubic yard of concrete, slump, and w/c ratio values are the results of Ellensburg laboratory tests.

*Increasd by 5 per cent for field application.

words, a follow-up system was necessary and was provided by the following means:

(a) The various concreting jobs in progress were constantly visited by a so-called "Chief Inspector," a construction man of wide experience and mature judgment, who passed on the various features of the work and particularly those of a practical nature, such as the sufficiency of the forms, the proper placement and splicing of reinforcing bars, and the most suitable consistency of concrete for the particular conditions to be met. By consulting with the contractor, the inspector, and the division engineer, the Chief Inspector was able to check improper practices at their sources and iron out many differences or controversies.

(b) The Construction Engineer made a regular practice of going over all or part of the work at least once a week during the period of activity.

(c) Inspectors were required to make 6 x 12-in. test cylinders in accordance with a definite procedure and schedule, and to see that they were properly cared for until collected by a truck sent out from the project laboratory. After being collected, the cylinders were stored in moist-sand curing vats up to the date of breaking.

(d) Each concrete inspector was also required to prepare a daily "Inspector's Report" and "Cylinder Report," on mimeographed forms, principally to keep the project office informed and provide a permanent record for future reference. The "Inspector's Report" embraced all the essential features of the work, including location, work performed, delays, weather conditions, details of the mix and consistency, etc., and provided opportunity for the inspector to state his personal views or air his particular troubles. The reports were promptly checked by the division office engineer, then referred to the division engineer and mailed to the project office, where they were carefully reviewed. If any irregularities of consequence or requests for advice or assistance were noted, the matters were generally handled by correspondence, using short stereotyped-form of letters, or by a trip to the field on the part of the man directing the laboratory operations. The same agencies were utilized in the event any breaks of the field test cylinders proved to be abnormal and their abnormality was unaccounted for.

(e) Additional field trips were made by the laboratory representative, at rather frequent intervals and without warning, to check up on the more technical details incident to securing the specified concrete mixes (such as proper measurement of aggregates, water, etc.) or to investigate the conditions on particular jobs where there was reason to believe, based on information emanating from the Construction Engineer, Chief Inspector, or other source, that the control system was not functioning as well as it might.

Concrete mix used and basis for selection. The concrete mix used on the greater portion of the canal lining work was a 1:2.4:3.6 by volume, dry rodded, with 3 per cent diatomaceous silica admixture, and 2-in. average slump. A 1:2:4 mix was first attempted but proved deficient in sand for the best workability

and counteracting the harshening effect of field segregation of the coarse aggregate. Another change made in the early stage of construction was the reduction of the maximum size of the gravel from 1½ in. to 1¼ in.

Impermeability, rather than strength, was the governing factor in the selection of the canal lining mix. While strength reflects many of the desirable properties of concrete and serves as a convenient general measure of value, it is not necessarily a criterion of watertightness. In the case of the canal lining, the latter quality was regarded as of greater import in lengthening the life of the concrete by rendering it more resistant to the disintegrating forces to which the lining will be subjected, including contact with flowing water during the irrigation season and exposure to severe frost and variable moisture conditions during the balance of the year. What little test data on impermeability, for the particular aggregates chosen, was available at the time it became necessary to determine the canal lining mix, indicated that a mix leaner than a one to six by volume could not be relied upon to furnish the desired degree of watertightness, notwithstanding the relatively high compressive strength (about 4,500 pounds per square inch) corresponding to the one-six mix. This conclusion was substantiated by laboratory tests later conducted to investigate the water-pressure-resisting properties of 4 x 12 in. concrete discs of various mixes, as previously mentioned. Water pressures up to 500 pounds per square inch were employed in the tests, principally in connection with the determination of suitable mixes for siphons designed to operate under unusually high heads. Fig. 20 shows the latest form of impermeability apparatus developed. It is without the scope of this article to describe the details of the apparatus or give the results obtained from the tests, except to refer to one feature bearing directly on the canal lining mix; namely, that the addition of diatomaceous silica to the extent of 3 per cent by weight of the cement brought about a marked improvement in the watertightness of the concrete, although the original purpose in employing the admixture in the leaner mixes was mainly to improve the workability and lessen the tendency for segregation.

Measurement of concrete ingredients. A careful measurement of the ingredients in each batch of concrete for canal lining was

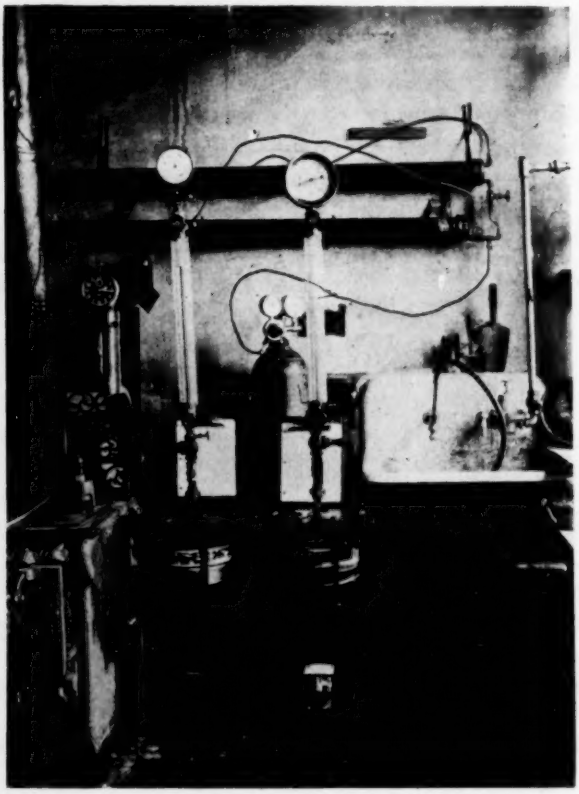


FIG. 20—IMPROVED TYPE OF APPARATUS FOR TESTING IMPERMEABILITY OF CONCRETE DISCS UNDER WATER PRESSURES OF 0-500 POUNDS PER SQUARE INCH

insisted upon. In all cases the sand was weighed and thus the problem of sand bulking was eliminated. The gravel was measured by weight or by volume, based on and occasionally checked by weight. Moisture in the aggregates, for determining the correct batch weights and accounting for the total water entering the concrete, was measured by means of apparatus embodying the water displacement principle, or by ordinary heating or alcohol-burning methods. The introduction of water at the mixer was gaged by the mixer man to bring the concrete to

the specified consistency or slump, the general practice being to regulate the mixer tank adjustment for the minimum water requirement and then add what little additional water was needed. This procedure was found to be the most practicable, and while on first thought it might seem to involve a material departure from rigid water control, a little reflection will reveal the fact that, with reasonably accurate measurement of the materials other than water, any variation in the water-cement ratio in bringing the concrete to the same consistency would be largely confined to the effect of variation in grading of the aggregates and would generally be insignificant. Considerable trouble was experienced by inspectors in determining the average amount of water added at the mixer, per batch of concrete, due principally to inefficient water regulating and measuring equipment on the mixers in use. In most cases the difficulties were wholly or partially overcome by calibrating the mixer tanks and supplementing the results with occasional check measurements of the mixer discharge by diverting it into a portable measuring tank.

Importance of controlling concrete consistency. Fortunately the contractors were as vitally interested as the Government in securing controlled concrete for the canal lining, inasmuch as consistency was a critical factor in the placement of the concrete on the side slopes. Even a variation of but 1 inch in slump made a marked difference in the results. If the slump was less than 2 in., the moving form left a honey-combed concrete; whereas a 3-in. slump produced a bulging and waving of the concrete. Best results were obtained with a slump of 2 to 2½ ins., a range which was quite consistently maintained by the mixer men after a little experience.

Field test data. The results of the 28-day breaks of field test cylinders on canal lining, for the 1928 construction season, are summarized in Table 2. Included in the table are average compressive strengths for the separate lining jobs and the work as a whole, a comparison between actual and predicted strengths, and data revealing the strength variations, including an improvised "Control Factor." Table 3 gives the compressive strengths of two series of 3 x 3 x 6 in. concrete test blocks which were cast

TABLE 2.—RESULTS OF 6 x 12-INCH TEST CYLINDERS—CANAL LINING—1928

Description	Contractor					Average of All Field Specimens (Moist Sand Cured)	Predicted Strength Based on Laboratory Control Curve
	C. F. Graff	General Construction Co.	S. H. Newell & Co.	Derbon Constr. Co.			
				Moist Sand Cured	Surface Treatment Cure		
Number of field test specimens	59	91	72	155	90	377	
Average reported W/C ratio	.77	.82	.83	.84	.84	.82	*.82
Average 28-day compr. strength	4359	4914	4572	4466	3755	4562	4400
Mean variation in strength was as follows:							
A. Per cent within 10 per cent of average strength	65%	62%	53%	51%	47%	56%	
B. Per cent within 15 per cent of average strength	87%	82%	68%	74%	74%	77%	
C. Per cent within 20 per cent of average strength	90%	98%	92%	85%	87%	90%	
Control factor $=\frac{A+B+C}{3}$	81%	81%	71%	70%	69%	74%	

*Water-cement ratio given represents average of field values reported and corresponds to laboratory water-cement ratio of about .87, the difference of .05 being due to aggregate absorption estimated at .5 per cent by weight.

TABLE 3.—COMPRESSIVE STRENGTH OF 3-IN. BY 3-IN. BY 6-IN. CONCRETE BLOCKS FROM CANAL LINING

Age at Test	From General Construction Company lining (Continuous sprinkling for 14 days)				From Derbon Construction Company lining (Cured by asphalt paint application—Hunt Process)			
	S. Slope	Floor	N. Slope	Average	S. Slope	Floor	N. Slope	Average
7 Days	3220	3610	3610	3480	4920	5305	4055	4760
14 Days	3780	4610	4000	4130	4330	5055	4330	4572
28 Days	4740	5000	4535	4758	5480	4000	4040	4507

NOTE: Lining containing blocks poured on July 20, 1928. Followed by 8 days of extremely hot weather, during which the temperature mounted to 110 degrees Fahrenheit and exceeded 100 degrees on 6 successive days.

and cured simultaneously as an integral part of the canal lining. One series is representative of water-cured lining, and the second of lining cured by the asphalt paint application (Hunt process). A striking feature of the test results in Table No. 3 is the gradual increase in strength of the water-cured specimens, as compared with the rapid hardening of the surface-treated blocks. As stated in the explanatory note, the block tests were carried on during a period of extreme summer temperatures. The slower-hardening of the water-cured blocks is accounted for mainly by the cooling effect of the continuous sprinkling.

Value of concrete control. Judging from the opinions expressed, there is little doubt in the minds of those connected with the concrete work, or of even the casual observers who witnessed the concreting operations or viewed the completed work, that the effect of the more systematic and precise concreting methods practiced was noticeably reflected in the finished product. (Figs. 21 and 22). The only question which remains, apparently, is whether the improvement realized will manifest itself in the form of decreased maintenance and increased life of the concrete to a sufficient extent to compensate for the additional effort expended, and while there is a general feeling of assurance that it will, the proof of the pudding is in the eating and time alone will tell. From the experience gained on the Kittitas division, this much at least may be said for control: (1) That it shows unmistakable evidence of improved concrete and may yield big financial returns; (2) That it brings forcefully to the attention of inspectors, and others engaged in directing the operations, the many influences affecting concrete in the making and the necessity for coordinating and controlling the various detail processes if concrete of uniformly high quality is to be produced; (3) That when control embodies properly made tests of laboratory and field specimens, it provides a definite and intelligent means for establishing the field mixtures and gauging the qualities of the final product, even though such specimens may not be truly representative of the concrete in the work; and (4) That it stimulates an interest in concrete and inspires further investigation, which in turn should eventually rid the manufacture of concrete of its major perplexities.

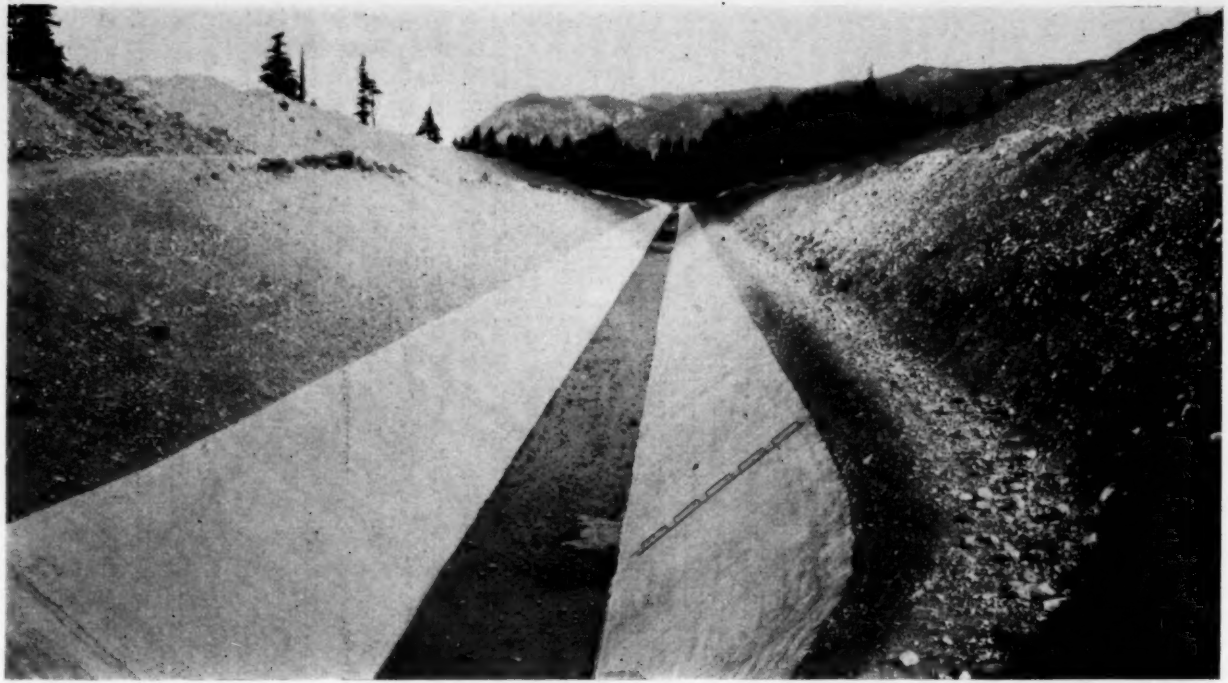


FIG. 21—LOOKING DOWN CONCRETE LINED SECTION OF MAIN CANAL FROM OUTLET OF PETERSON CREEK SIPHON. NOTE SAFETY LADDER ON RIGHT HAND SIDE SLOPE. SAFETY LADDERS PLACED EVERY 250 FT. ON ALTERNATE SIDE SLOPES IN LINED SECTIONS OF THE CANAL

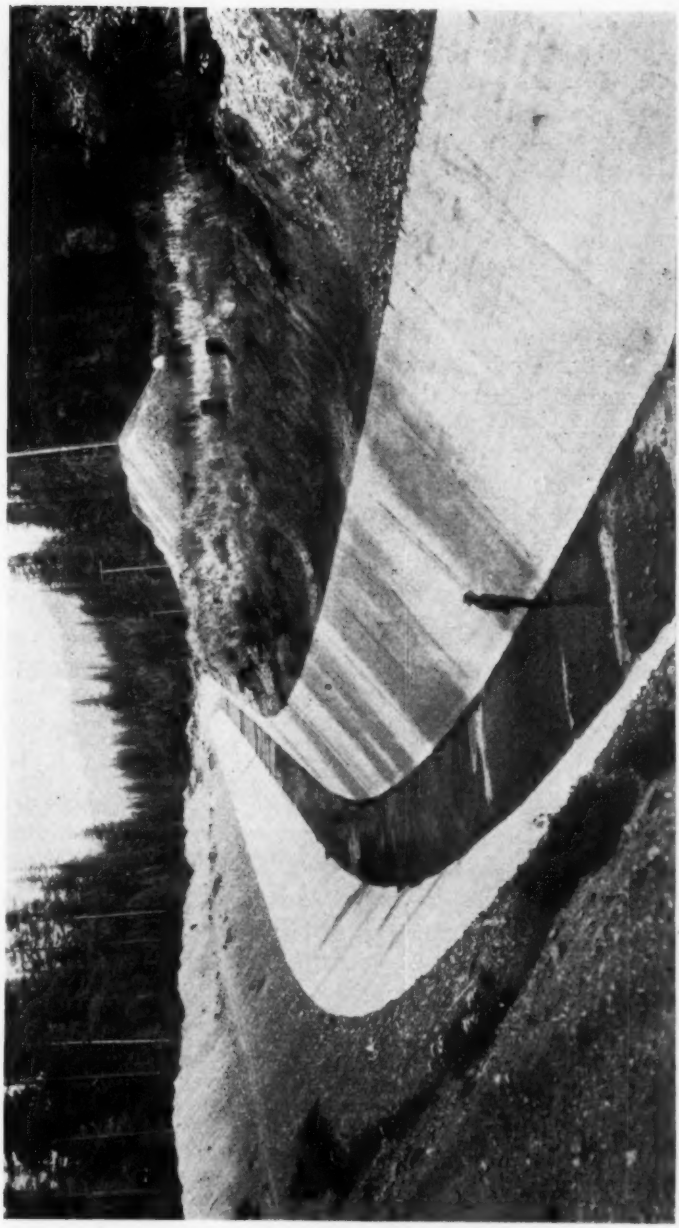


FIG. 22—ANOTHER SECTION OF CONCRETE LINED CANAL, LOOKING DOWN THE MAIN CANAL NEAR EASTON, WASHINGTON. NOTE TRUE ALIGNMENT OBTAINED BY USE OF MOVABLE CONCRETE PLACING PLATFORM

Personnel. The construction of the Kittitas division of the Yakima project was under the direction of Construction Engineer Walker R. Young. The development of technical control procedure for the concrete work and the prosecution of the laboratory work were under the general direction of Office Engineer Arthur Ruettgers. Division Engineer A. A. Whitmore was in direct charge of the reach of Main Canal which included the lining work contracted to C. F. Graff, S. H. Newell & Co., and the General Construction Co. The reach of canal comprising the lining constructed by the Derbon Construction Co. was in charge of Division Engineer V. W. Russell. The principal designing work for the Bureau of Reclamation is done in the Denver office under the general supervision of J. L. Savage, Chief Designing Engineer. All engineering and construction work is under the general supervision of R. F. Walter, Chief Engineer, with headquarters at Denver, and all activities of the bureau are under the general charge of Dr. Elwood Mead, Commissioner, with headquarters at Washington, D. C.

Readers are referred to the JOURNAL *for February, 1931, for discussion which may develop. Such discussion should reach the Secretary by January 1, 1931.*

Construction and Design Features of Haydite Concrete.

BY F. E. RICHART* AND V. P. JENSEN†

INTRODUCTION

General Statements: The development of the use of reinforced Haydite concrete has introduced various problems in design and construction with this material. While light weight is the property that makes desirable the use of Haydite concrete, the engineer and contractor require information on other properties, particularly those affecting strength, durability and ease of construction. There is a demand for information on proportions to produce a specified strength and workability, and on methods of quality control. The designer wants, in addition to data on unit weight and strength, information as to the elastic behavior of the material and its action in a structure. The effect of the relatively low modulus of elasticity of Haydite concrete is of importance, and may have a considerable influence upon the economy of design.

A recent paper by the authors, reporting an investigation of Haydite concrete in progress at the University of Illinois, gave test data on compressive strengths, bond and diagonal tension resistance, together with various other strength properties of Haydite concrete.‡ An attempt will be made in this paper to analyze certain of these test data and to apply the results to design and construction work.

The investigation mentioned above is being made at the Materials Testing Laboratory, University of Illinois, in cooperation with the Western Brick Co., Danville, Illinois, manufacturers of "Western" Haydite aggregates.

---

*Research Associate Professor of Theoretical and Applied Mechanics, University of Illinois.
†Research Assistant in Theoretical and Applied Mechanics, University of Illinois.
‡Proc. A. S. T. M., Vol. 30, Part II, 1930. "Tests of Plain and Reinforced Haydite Concrete."

The work is being conducted by the authors under the administrative direction of Dean M. S. Ketchum, Director of the Engineering Experiment Station, and Professor M. L. Enger, Head of the Department of Theoretical and Applied Mechanics, University of Illinois. I. N. Doughty, Manager of Research, and Frank Payne, Engineer, of the Western Brick Co., have represented their organization as an advisory committee on the work.

PROPERTIES OF MATERIALS

Aggregates: The Haydite aggregates to which this discussion applies are the "Western" fine or "A" size material, passing a $\frac{3}{16}$-in. round hole screen, and the coarse or "C" size, retained on the $\frac{7}{32}$-in. screen and passing the $\frac{3}{4}$-in. screen. The range in values of the properties of a number of lots used are given in Table 1. The apparent specific gravity of material passing the 200-mesh sieve was found to be 2.56, indicating that the absolute specific gravity of the material is as high or higher. The coarse particles, with an apparent specific gravity of 1.25 to 1.32, evidently have about 50 per cent porosity. The apparent specific gravity of the material increases as the size of particle decreases. There are usually a few particles in a sample that will float in water. The specific gravity of a graded sample is seen to be the average of individual values that vary considerably and is not so definite a property as that of a homogeneous material.

Types of Concrete Mixture: Reference will be made frequently to two types of mixture, one made with a natural sand and coarse "C" Haydite, which will be denoted as "C-Haydite" concrete; the other made with fine "A" Haydite and coarse "C" Haydite, denoted as "All-Haydite" concrete. The sand used in the first mixture was a torpedo sand from Covington, Indiana, having a fineness modulus of 3.08, unit weight, loose, dry, of 106 lb. per. cu. ft., absorption of 1.0 per cent, and specific gravity of 2.67.

Absorptive Properties of Aggregates: The absorption of mixing water, usually a minor factor in the production of concrete with sand, gravel and stone aggregates, becomes a matter of real importance when the aggregates are capable of absorbing a large amount of water. This presents a two-fold problem, of which one part concerns the drying of the concrete and consequent

change in workability due to rapid absorption of water by the Haydite during and immediately after mixing; the other involves the determination of the true water-cement ratio, or some related property, which varies as the absorption of the mixing water proceeds. The latter variation obviously adds some difficulty to the use of water-cement ratio as a strength control.

The tests of absorption made thus far have been of a preliminary sort; however, a more thorough study is now being started and should furnish needed data. The tests indicated one unexpected phenomenon; the fine Haydite absorbed a larger percentage of water by weight in a given length of time than did the coarse material. Considering that the material consists of a mass of closed cells of infinitesimal size, it is seen that in view of the greater surface area of the fine material, a certain depth of penetration by the water should produce the greater absorption in the fine material. It is probable that the total absorption over a long period would be greater for the coarse material; tests up to 7 days showed continuing absorption at the end of the period. It is also likely that the absorption by the very fine material, such as that passing the No. 100 sieve, would be small due to the lower porosity.

The absorption tests made were on dry material and on material with various initial moisture contents. The procedure used with the coarse aggregate was the usual immersion method, using a covered wire basket suspended from one arm of a balance. The material was surface dried by rolling it on a paper towel. The method finally used with the fine material was to place a sample of the soaked material in a centrifuge, which was used to remove surface water. The criterion for surface dryness was the ability of the material to run freely through the fingers. In both tests the amount of absorbed water was found by oven-drying.

Fig. 1 (a) shows the absorption determined for dry fine and coarse Haydite for various periods of immersion. Fig. 1 (b) shows similar data for both dry and initially moist materials for various immersion periods. It is clear that Haydite does not have a *fixed* amount of absorption in a given time, as usually assumed for ordinary aggregates, but the amount depends upon the initial moisture content. Moist aggregates show a larger total absorption than initially dry ones, especially in the case of

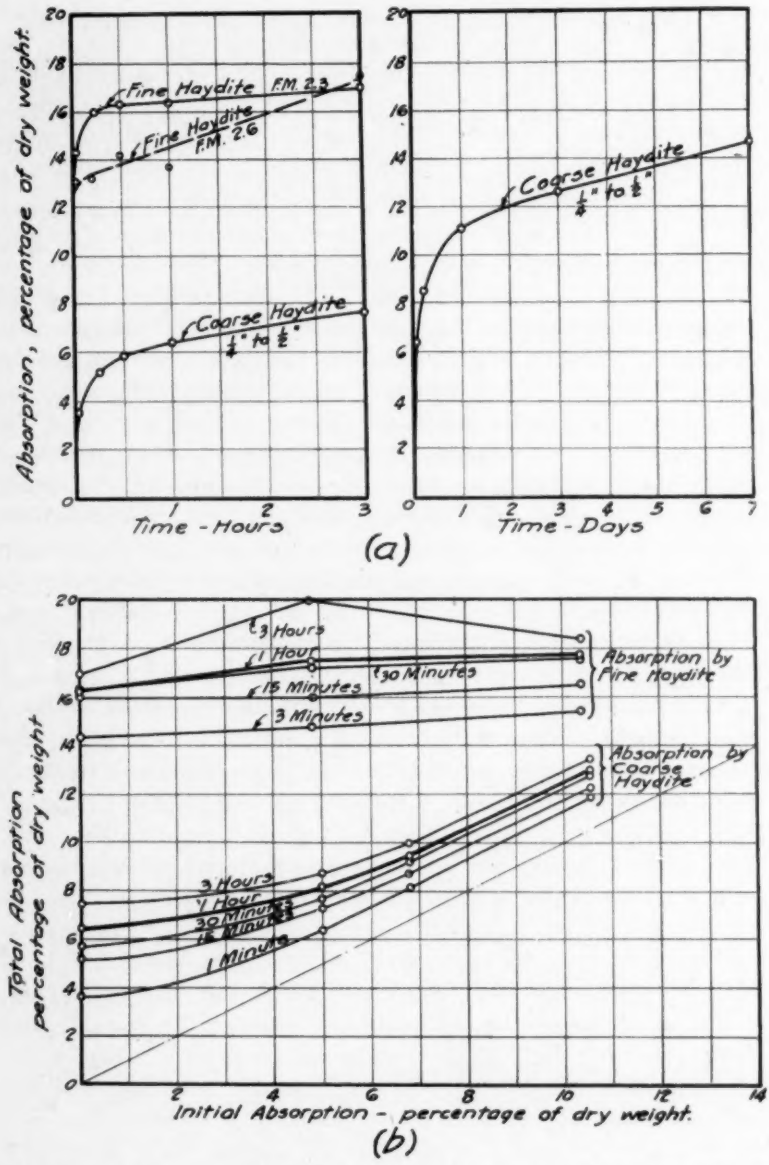


FIG. 1—(a) ABSORPTION OF WATER BY INITIALLY DRY HAYDITE AGGREGATES FOR VARIOUS PERIODS OF IMMERSION. (b) ABSORPTION BY HAYDITES HAVING VARYING INITIAL MOISTURE CONTENTS

the coarse material. The fine material reaches its absorptive capacity more quickly than the coarse and is less affected by initial moisture conditions.

The effect of a variation in water-cement ratio due to error in absorption allowance may be seen from an example. In a one-bag batch of a 1:2:3 mixture, there would be roughly 245 lb. of Haydite. An error of 2 per cent by weight of aggregate in the absorption allowance would change the amount of free water by 4.9 lb. and the value of w/c by $\frac{4.9}{62.4} = 0.08$. With a water-cement ratio of 1.0 this will cause a variation in strength of 15 per cent or more.

There is little information regarding the period of time that aggregates should be immersed in water to produce an absorption equal to that taking place during the mixing and placing of concrete. Periods varying from 15 minutes to 3 hours have been assumed by various investigators, without great difference in result when ordinary aggregates were used. Observation of fresh concrete in forms indicates that insofar as water content fixes the voids in the concrete, the mass takes its final volume (neglecting subsequent shrinkage of the order of 0.1 to 0.2 per cent of volume) within 15 minutes after the concrete is placed. Changes in water-cement ratio due to further absorption by the aggregates may affect the process of hydration and thus affect the strength. An estimate of this effect has led to the use in this investigation of an absorption allowance corresponding to a one-hour immersion test. Values for one-hour absorption for material with various initial moisture contents are shown by the heavy curves of Fig. 1 (b).

It will be noted that Fig. 1 (b) refers to initial absorbed moisture, not total moisture content. The proportions of absorbed and free moisture in a sample will depend entirely upon how the moisture content has been taken on. If a wet sample is drying out the amount of absorbed moisture will be high; a sample just wet down will contain mostly free surface water.

CONSTRUCTION FEATURES

Relations Between Water-Cement Ratio and Strength: In a study of the relation between water-cement ratio and strength

for Haydite concrete, several series of cylinder tests were made, including mixtures with sand and gravel aggregates, sand and coarse Haydite, and fine and coarse Haydite. These were made of several proportions and consistencies and tested at ages of 7 and 28 days. Two groups were made with fine and coarse Haydite, one with oven-dried material, the other with moisture contents of 6 per cent in the coarse and 27 per cent in the fine material. In determining the water-cement ratios, absorption allowances have been used as follows: for sand and gravel, 1 per cent by weight; coarse Haydite, dry, 7 per cent, moist, 9 per cent; fine Haydite, dry 14 per cent, moist, 20 per cent. Data from the 28-day tests are plotted in Fig. 2. All of the points fall within a fairly narrow zone on the diagram, though there are definite differences in the average curves for the four series of tests. The All-Haydite concrete made with moist aggregates appears to be consistently stronger than that made with dry Haydite, and as strong as that made with sand and gravel. The difference in the Haydite concretes may be due to a better bond between the moist particles and the cement paste than that obtained with the dry particles, to differences in absorption not fully accounted for in the corrections applied or to differences in the water-cement ratio relation. All of these curves give strengths considerably above the values recommended in the Joint Standard Building Code of the American Concrete Institute for use with average materials. These rather high strengths call attention to the cement used, which was a new lot of standard Universal cement, passing the Standard Specifications for Cement current when the tests were made. Tensile strengths of standard Ottawa mortar briquets were: at the age of 7 days, 258 lb. per sq. in.; at 28 days, 370 lb. per sq. in.

It is recommended that in the design of Haydite concrete when very careful absorption determinations are not made and the work is done under ordinary conditions of supervision, somewhat lower strengths be assumed for a given water-cement ratio than those given in Fig. 2. The values recommended in the Joint Standard Building Code noted above, which are probably sufficiently conservative, are as follows:

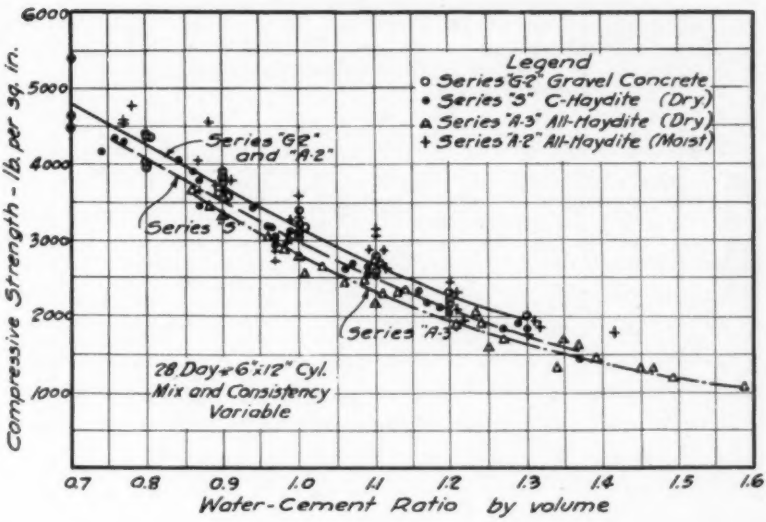


FIG. 2—RELATION BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH FOR THREE TYPES OF CONCRETE

Water-Cement Ratio		Compressive Strength* lb. per sq. in.
By Volume	Gallons of Water per Sack of Cement	
1.10	8¼	1500
1.00	7½	2000
0.90	6¾	2500
0.80	6	3000

*From tests of 6 by 12 in. cylinders, moist cured for 28 days at 70° F., tested moist.

The indication in Fig. 2 that greater strength is obtained through the use of moist Haydite aggregates than with dry ones, even when a logical correction is made for differences in absorption, is borne out by several other groups of tests. This favors the practice of pre-wetting of aggregates in the stock-pile previous to placing them in the mixer, which has been done, however, for the primary purpose of securing better and more uniform workability and to prevent undue drying out of the concrete after

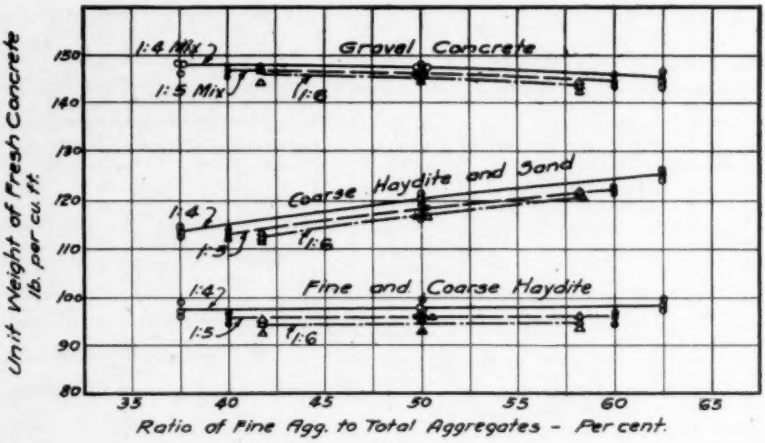


FIG. 3—UNIT WEIGHT OF GRAVEL AND HAYDITE CONCRETES

it was placed. Such pre-wetting, unless very systematically done, may increase the difficulty of applying proper absorption corrections where a close control of strength is required.

Proportions and Workability. Some users of Haydite aggregates have run into difficulty due to an attempt to use as large a proportion of coarse Haydite as would be used with 1½-in. gravel. It has been established by experience and tests that the amount of coarse aggregate usable decreases as the size of particle decreases, at least below the 1-in. size. While an aggregate of ½-in. size may contain the same percentage of voids as one of 1½-in. size, it is obvious that the size of the voids is smaller in the ½-in. material and will not accommodate sand grains without separation of the coarse aggregate particles. The proportion of coarse to total aggregates recommended by the Portland Cement Association in "Design and Control of Concrete Mixtures," 3rd. Ed. 1929, is 0.50 to 0.70 for coarse aggregate of maximum size of 1-in. or over; 0.40 to 0.60 for a maximum size of ¾-in.; and 0.30 to 0.45 for a maximum size of ⅜-in. Proportions of "C" Haydite (which is composed of material passing a ¾-in. round hole screen) varying generally from 40 to 60 per cent of the total were used in the tests represented by Fig. 2. Considering the resulting

workability obtained with the use of an excess of fine aggregate and also the accompanying increase in weight of the sand and "C" Haydite mixture, it is believed that a mixture of 45 per cent fine and 55 per cent coarse is the most desirable combination, at least with the sand and Haydite mixtures. For All-Haydite concretes it may be just as economical to use equal parts of fine and coarse material.

Data of C-Haydite and All-Haydite mixtures (see Series S and A-3 of Fig. 2) are given in Table 2 as a guide to proportions and accompanying slumps usable with various water-ratios. The materials used were in all cases initially dry. If moist aggregates are to be used, bulking and moisture content tests should be made, so that volumes of moist material containing solids equal to those of the dry materials may be used. The bulking effect is small for the coarse Haydite and usually will not exceed 5 or 6 per cent, but for the fine Haydite the bulking may be important. Thus the fine Haydite weighing 55 lb. per cu. ft. by dry loose measure, weighs 51 lb. per cu. ft. with 27 per cent of moisture present. This 51 lb. consists of 40.1 lb. of dry Haydite and 10.9 lb. of water. To obtain 55 lb. of dry Haydite in the mixture requires $\frac{55}{40.1}$ or 1.37 cu. ft. of the moist material. With this 37 per cent bulking in the fine aggregate and assuming a 5 per cent bulking in the coarse, for a mix of 1:2:3 concrete as listed in Table 2, the volume proportions with the moist materials should be 1:2.74:3.15. Similarly, the quantities required per cubic yard of concrete as given in Table 2 would be multiplied by the ratios of 1.37 and 1.05 for the fine and coarse materials, respectively.

The use of moist aggregates just described will naturally affect the water requirements. In a one-bag batch the 2.74 cu. ft. of fine aggregate contain 10.9 lb. of water per cu. ft. or 29.9 lb. This must be considered in computing the amount of water for mixing and absorption requirements.

The quantities of materials in Table 2 contain no allowance for waste or for settlement of material in forms. As explained, the aggregate quantities must be increased for bulking when moist aggregates are used. If these proportions are used without

correction for bulking, a richer and stronger mix will result, and all quantities of materials, including the cement, will be increased. The amount of such increase, in per cent, is roughly equal to the per cent bulking of the fine aggregate times the ratio of fine to total aggregates.

Table 2 shows a range of workabilities as shown by values of slump from 1 to 10 inches. For making test beams with fairly heavy reinforcement, very satisfactory placing of the concrete was accomplished with slumps of 6 and 7 inches. Good surfaces were obtained next to the forms and there was practically no honey-combing or segregation of the materials. For slabs and large beams slumps of 4 to 6 inches should give satisfactory workability.

Unit Weight of Concrete: Data on unit weight of freshly placed concrete as found from test cylinders are given in Fig. 3. It is seen that the weights of gravel and All-Haydite concretes do not vary greatly with changes in proportions and consistencies corresponding to those of Table 2. The values shown in Fig. 3 are for concrete made with dry aggregates. The weight of All-Haydite concrete made with moist aggregates was 3 to 6 lb. per cu. ft. greater than that of Fig. 3, which is further evidence that the total absorption of moist aggregate is greater than for that initially dry. The increase in weight of "C"-Haydite concrete with increasing amounts of natural sand is self-explanatory.

DESIGN CONSIDERATIONS

General Considerations: Of the several phases of concrete design those of primary importance are—first, the selection of a concrete strength, second, the determination of the necessary and usable proportions of materials, and third, the actual design of the structural members. Data pertaining to the first and second phases have been presented and further discussion of economy as it relates to them would necessarily involve relative prices of materials, relative quantities of the different materials which could be used to produce a desired strength and consistency of concrete, and proportional costs of raw materials and concrete in place. Current local prices and the needs of individual jobs will govern the comparisons to be made and therefore this section

will be devoted entirely to the factors which affect the design of the structural members. These factors are lightness in weight and low modulus of elasticity.

In the following analysis the symbols and notation are those in general use, as defined, for example, in the A. C. I. Joint Standard Building Code, Section 602. In addition, use has been made of the relation *Resisting Moment* = Kbd^2 for balanced reinforcement, also the subscript g has been used with terms referring to gravel concrete.

It may be noted that the comparisons to follow involve values of strength and modulus of elasticity from tests of cylinders rather than of beams. The limited amount of beam test data available are in accord with the analyses given; Haydite concrete beams show larger values of k and consequent smaller values of j, and increased strains and deflections at a given load, as compared to gravel concrete beams. Haydite concrete beams tested in studies of diagonal tension showed no initial failures at the extreme fibre in compression, even though percentages of longitudinal reinforcement (structural grade) as great as 2.8 were used, and tensile failure of the steel was developed. Obviously, beam and slab tests corresponding to the range of designs considered here would be impracticable, and such tests have not been made. Instead, the authors have felt justified in determining properties of the material and in applying the results by means of well-established theory of the behavior of such members.

Effect of Lightness in Weight: Unit weights of concrete made of gravel and sand, coarse Haydite and sand, and of fine and coarse Haydite are shown in Fig. 3. For ordinary mixtures "C"-Haydite concrete will weigh 80 per cent, and All-Haydite concrete 67 per cent, of the weight of gravel concrete. The effect of a reduction in dead load depends upon the percentage of dead to total load and upon the manner in which the designer may take advantage of the reduced load. His beam sizes, spans, or slab thicknesses may be limited by considerations other than stress, in which case it may not be possible to obtain full advantage.

Comparison has been made in Table 3 of the three kinds of concrete (gravel, "C"-Haydite, and All-Haydite) for ratios of dead load to total load varying from 60 to 30 per cent, upon the conditions that the resisting moment which must be developed is

proportional to the load per sq. ft. of floor area, and that b and d for slab or beam are the same for all three kinds of concrete. The figures shown are ratios of total loads to be carried and are equal to the ratios of resisting moments to be developed when the span is the same for all three concretes. Values of j for "C"-Haydite and All-Haydite concretes with balanced reinforcement are shown in the following section to be approximately 97 and 95 per cent respectively of j for gravel concrete. Haydite concretes are shown to require higher percentages of steel for balanced reinforcement as a consequence of higher values of n. Therefore in the comparison of Table 3, which imposes constant span and depth of slab, a decreased bending moment due to decreased load results in a lowering of the percentage of steel required for the Haydite slabs and brings the values of j for Haydites nearer to the value for gravel than is indicated by the proportions of 97 and 95 per cent. The relative percentages of steel required for the three concretes are thus shown to be approximately equal to the values given in Table 3 of relative percentages of resisting moment which must be developed.

The effect of taking advantage of the reduced weight of Haydite concrete by reducing the depth of the slab is to produce an additional secondary reduction in the values given in Table 3 of from 1 to 4 per cent, the higher percentage being for the greatest percentage of dead to live load. In a comparative design of gravel and Haydite concrete in which d is varied and balanced reinforcement is maintained the additional effects of concrete strength and variation of E enter the problem. These effects are discussed separately in the following section.

The percentage of reduction in column loads to be carried when Haydite concrete is used in place of gravel concrete is somewhat greater than those indicated for slabs in Table 3, due to the reduction factor which is applied to the live loads under many building codes. The effect of such a live load reduction factor becomes greater as the number of stories between the column to be considered and the roof is increased. Since the column is designed for the remaining live load and the dead load, a decrease in the latter becomes quite important.

A considerable economy may result from dead load reduction under certain conditions of design due to the ability to use a cheaper type of foundation than would have been required for the heavier dead load. Complete data concerning the individual job would necessarily have to be available for a determination of this possibility.

Modulus of Elasticity of Haydite Concretes: Experimental values of initial moduli of elasticity of concretes made with gravel and sand, coarse Haydite and sand, and fine and coarse Haydite are shown in relation to compressive strength in Fig. 4 (a). Each value is the average of 3 tests. Mixes varied from 1:4 to 1:6, percentages of fine aggregate to total aggregate from 37.5 to 62.5, and slumps from 1 inch to 10 inches. It will be seen that for each kind of concrete the variation in E with strength may be represented by a straight line for strengths between 2000 and 4000 lb. per sq. in. It will also be noted that the moduli for "C"-Haydite and All-Haydite concretes average about 75 and 55 per cent, respectively, of the values for gravel concrete.

Fig. 4 (b) shows the relation between the moduli found by test and the values which are obtained by using the A. C. I. building code value of $1000f'_c$ for gravel concrete and values 75 and 55 per cent as great for "C"-Haydite and All-Haydite concretes, respectively. As another approximation, values of constant moduli of 3,400,000 for gravel, 2,500,000 for "C"-Haydite, and 1,900,000 for All-Haydite concrete are shown in the figure for comparison with the experimental and A. C. I. values. The three relations between E and strength will be used later in comparative studies.

For a more complete study of the possibilities of variation of secant moduli and to give information concerning relative deformations of the three concretes, the stress-strain curves of Fig. 5 are presented. These are typical curves taken from individual 6 by 12-in. cylinders of varying mix and consistency. Curves were obtained by means of an attached extensometer and a semi-autographic recording device. A constant ultimate unit deformation of about 0.0015 was found for gravel concrete of all strengths except those considerably below 2000 lb. per sq. in., this value being in agreement with numerous previous tests.

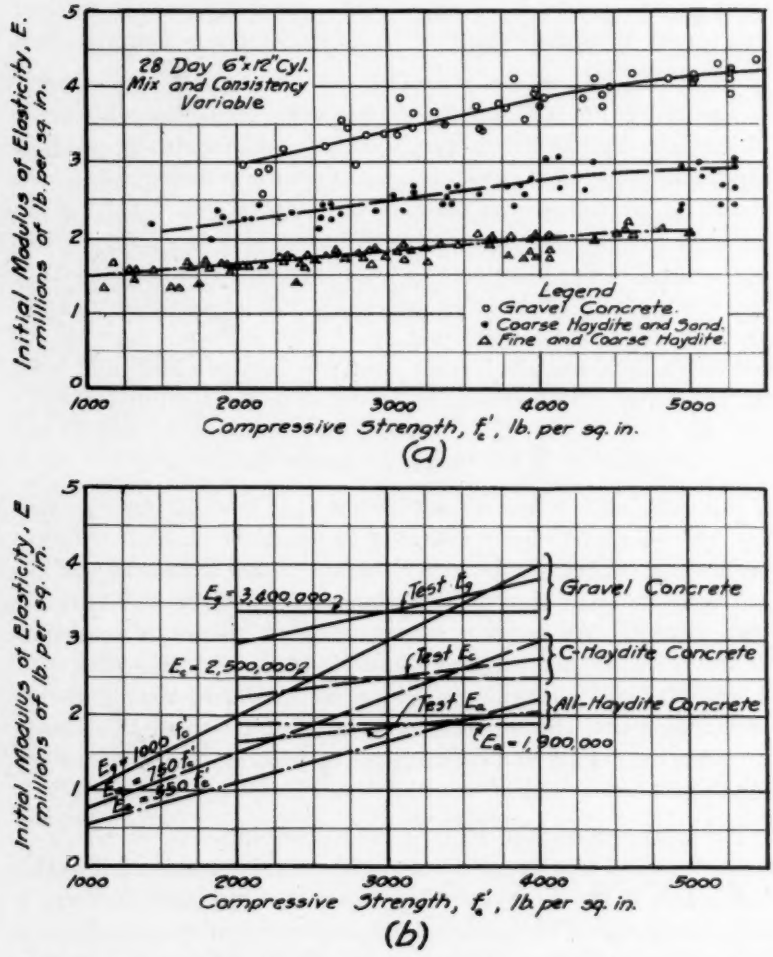


FIG. 4—RELATION BETWEEN INITIAL MODULUS OF ELASTICITY AND COMPRESSIVE STRENGTH FOR THREE TYPES OF CONCRETE

Ultimate unit deformations of the Haydite concretes are shown to be greater than those of gravel concrete, the proportional increase being greater for the concretes of higher strength. Deformation of All-Haydite concrete shows an increase over that of "C"-Haydite concrete similar to the increase in deformation of "C"-Haydite over that of gravel concrete. A consideration of the nearly straight stress-strain curve for high-strength gravel concrete will show that concretes having initial moduli 75 and 55 per cent as great must necessarily receive higher deformations in order to develop the same stress as the gravel concrete.

The curves of Fig. 5 have been replotted in Fig. 6 with the abscissas for the Haydite concrete reduced by the differences in horizontal intercepts of the tangents which represent the initial moduli of these concretes and gravel concrete. In other words, all curves have been brought approximately to a common tangent, that for an intermediate grade of gravel concrete. The curves as represented thus are scarcely more varied than is to be expected from a group of individual cylinders made with a single kind of aggregate. The similarity of these curves leads to the conclusion that for deformations up to 50 per cent of the ultimate deformation the relations of secant moduli of Haydite and gravel concretes are essentially the same as those of initial moduli. A further conclusion is that the primary difference in deformations is the difference in "elastic" deformation (deformation up to the line for initial modulus) as indicated by the ratios 75 and 55 per cent, and that the difference in "plastic" deformation (remaining deformation) is slight and of secondary importance. Since the "plastic" deformation gives an indication of the rate of breaking down of the structure it would seem that the Haydite particles themselves do not affect the rate of internal local failure and final complete rupture of plain concrete in compression.

Effect of Low Modulus of Elasticity on Design of Beams and Slabs: Comparative properties and design factors of rectangular beams and slabs have been computed and tabulated for gravel, "C"-Haydite and All-Haydite concretes having compressive strengths of 2000, 2500, 3000 and 3750 lb. per sq. in., using values of E from Fig. 4 (b). While a comparative design based upon the test values of E should probably give the truest indication of

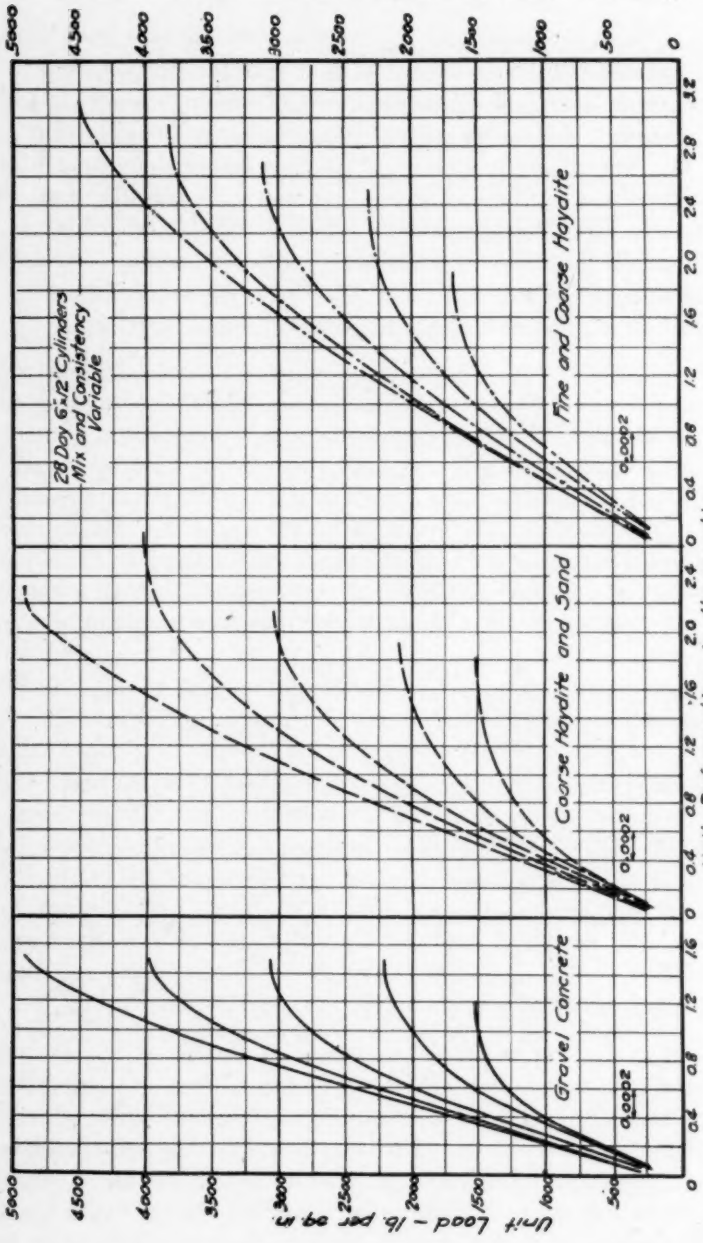


FIG. 5—STRESS-STRAIN CURVES FOR THREE TYPES OF CONCRETE

the differences in the concretes and their resulting behavior in flexure, the designer must necessarily use a codified value of E, and therefore the comparisons given in Tables 4, 5 and 6 are based on three different assumptions, respectively; (1) using test values of E, (2) using three proportions of the A. C. I. building code value of E, and (3) using constant value of E for each material. It is to be noted that the comparisons made in these tables are for the purpose of determining the effect of variation in E only and do not include the additional effect of lightness in weight in reducing the load to be carried and the section required.

In section A of Table 4, which is based upon experimental values of E, balanced reinforcement, $f_s = 20{,}000$ lb. per sq. in., and $f_c = 0.40\, f'_c$, the factors, n, k, j, p, and K are given for all three kinds of concrete. It will be seen that the lowered E and increased n for Haydite, while causing a slight decrease in j and a considerable increase in k and p, have the effect of increasing considerably the resisting moment factor K. The slab and rectangular beam comparisons which follow in the table are based upon various design limitations.

In section B, Table 4, under the heading "Slab Comparison Based Upon Constant Resisting Moment, b constant, d varies," are given figures which are intended to show the net effect of the changed design factors for Haydite concretes. These have been computed as follows:

Slab with Variable Depth, d.

With balanced reinforcement,

$$R.\ M.\ (\textit{Resisting Moment}) = Kbd^2 = 12\ Kd^2$$

$$d = \left(\frac{R.\ M.}{12\ K}\right)^{\frac{1}{2}}$$

For a constant resisting moment the ratio of depth, d, required for Haydite concrete slabs to depth, d_g, required for gravel concrete is,

$$\frac{d}{d_g} = \left(\frac{K_g}{K}\right)^{\frac{1}{2}}$$

Ratios of $\frac{d}{d_g}$ for "C"-Haydite concrete are shown in Table 4 to vary from 92 to 91 per cent and for All-Haydite concrete to

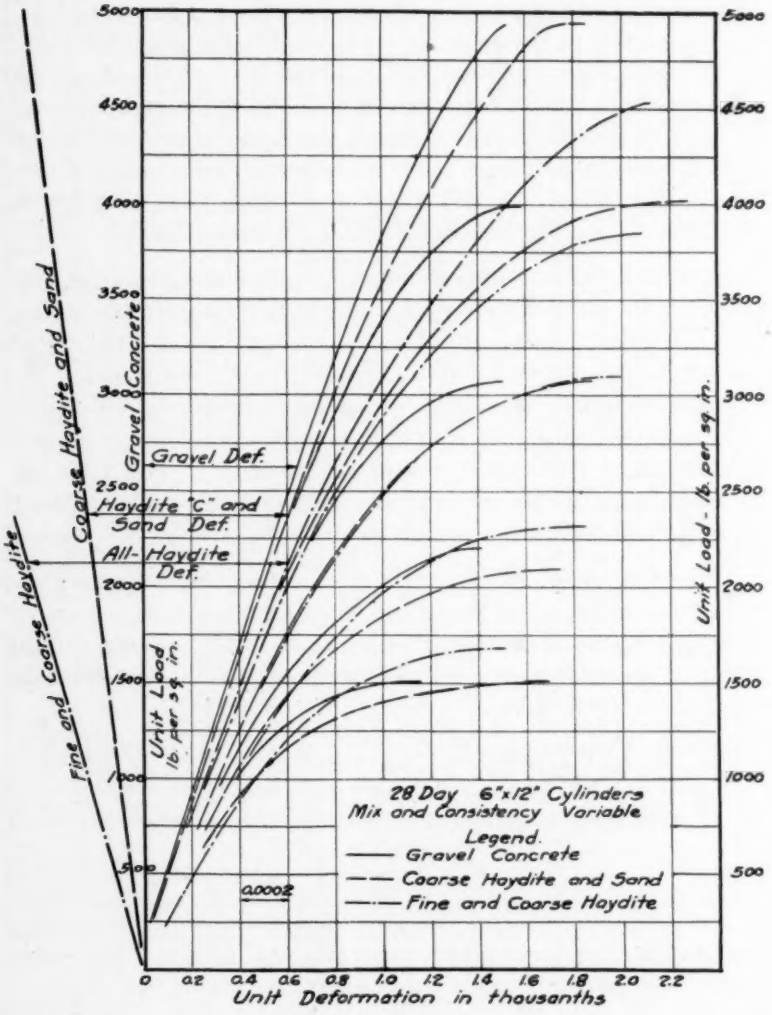


FIG. 6—MODIFIED STRESS-STRAIN CURVES FOR THREE TYPES OF CONCRETE

vary from 84.5 to 87.5 per cent. Percentages of total volume of concrete required would be from 1 to 3 per cent higher than these percentages of depth due to a constant thickness of covering.

Ratios of steel areas, A_s, required for Haydite slabs to steel areas, A_{sg}, required for gravel concrete are net ratios based on the increased p required for balanced reinforcement in Haydite and the reduced d as shown by the ratio $\frac{d}{d_g}$.

Thus:

$$\frac{A_s}{A_{sg}} = \frac{d}{d_g} \cdot \frac{p}{p_g}$$

Percentages of $\frac{A_s}{A_{sg}}$ (Table 4, part B) show for this comparison a requirement of from 111 to 110 per cent of steel area for "C"-Haydite concrete and from 123.5 to 121.5 per cent for All-Haydite concrete. The total effect is then to develop the same resisting moment with "C"-Haydite concrete with d reduced 8 to 9 per cent and A_s increased 11 to 10 per cent, and with All-Haydite concrete with d reduced 15.5 to 12.5 per cent and A_s increased 23.5 to 21.5 per cent.

Section C of Table 4, which is headed "Slab and Rectangular Beam Comparison Based upon Constant b and d for All Concretes," applies to the case in which a possible reduction in depth of slab is not utilized. It shows that with "C" Haydite concrete an increase of 18 to 17 per cent in resisting moment is obtained by the use of 21 to 20 per cent more steel, and that with All-Haydite concrete an increase of 39 to 31 per cent in resisting moment is obtained by an increase of 46 to 39 per cent in steel. The exact value of the increased carrying capacity or possibility of increased span length which is purchased in this case by the use of a higher percentage of steel is not at once easily determined as a simple percentage. If, however, no increase in resisting moment is desired, a constant resisting moment with constant depth of section may be provided with a Haydite concrete slab by the use of slightly more steel than that required by gravel concrete. This is due to the slight difference in j for the two materials, an effect due only to variations in modulus of elasticity. The com-

pensating effect of a reduction in weight in reducing the steel required with Haydite concrete is considered in Section 12.

In Section D of Table 4 comparisons of rectangular beams are based upon the condition that it is possible to reduce both b and d and that b and d for Haydite concrete beams are proportional to b and d for those of gravel concrete. Calculations were made as follows:

Rectangular Beams.

With balanced reinforcement,

$$\begin{aligned} R.\,M. &= Kbd^2 \\ b &= Constant \times d = Cd \\ bd &= Cd^2 \\ R.\,M. &= CKd^3 \\ d^2 &= \left(\frac{R.\,M.}{C\,K}\right)^{2/3} \end{aligned}$$

For a constant resisting moment,

$$d^2 = Constant \times \left(\frac{1}{K}\right)^{2/3}$$

$$\frac{bd}{(bd)_g} = \frac{d^2}{d_g^2} = \left(\frac{K_g}{K}\right)^{2/3}$$

These area ratios, $\frac{bd}{(bd)_g}$ for "C"-Haydite concrete are shown to vary from 89 to 90 per cent and for All-Haydite concrete to vary from 80 to 83.5 per cent of gravel areas.

Net ratios of steel areas, A_s, required for Haydites to areas, A_{sg} required for gravel concrete are 107 to 109 per cent for "C"-Haydite and 117 to 116 per cent for All-Haydite concretes. For these computations,

$$\frac{A_s}{A_{sg}} = \frac{bd}{(bd)_g} \cdot \frac{p}{p_g}$$

giving ratios of steel areas based on the reduced beam section as was done in the case of slabs of variable depth.

The comparative design ratios given in Table 5 using proportional A. C. I. Code values of E, and in Table 6 using constant values of E, were all computed in the manner described for Table 4.

It is to be noted that the comparative design ratios in Tables 5 and 6 do not differ greatly from those based on test values of E in Table 4, the largest difference occurring with the proportional A. C. I. Code values for 2000-lb. concrete where the greatest divergence in E is to be found (see Fig. 4 (b)). Actual percentages of steel, however, vary considerably for the lower strength concretes.

Combined Effect of Lightness in Weight and Low Modulus of Elasticity on Slab and Beam Design. In general a design in Haydite concrete will permit advantage to be taken of reduced dead load and must necessarily be made on the basis of actual values of E. Comparative design ratios are shown in Table 7 based on proportional A. C. I. Code values of E, for all concrete strengths, and for a range of ratios of dead load to total load from 0.50 to 0.20. Percentages of resisting moment required for Haydite to resisting moment required for gravel, $\frac{R.\ M.}{(R.\ M.)_g}$, have been taken from Table 3. Percentages given in section B of Table 7 for slabs with balanced reinforcement show a requirement for "C"-Haydite concrete of 88 to 91 per cent of the depth of gravel concrete slabs with corresponding values of 105 to 108 per cent of the steel areas for gravel concrete. For All-Haydite concrete similar percentages of depth are 80 to 85, with 111 to 117 per cent of steel. The analysis for variable resisting moment is similar to that given for Table 4.

Thus for a variable resisting moment, $R.\ M.$,

Slab comparison:

$$\text{depth ratios,} \quad \frac{d}{d_g} = \left(\frac{K_g}{K} \cdot \frac{R.\ M.}{(R.\ M.)_g}\right)^{1/2}$$

$$\text{and steel ratios,} \quad \frac{A_s}{A_{sg}} = \frac{d}{d_g} \cdot \frac{p}{p_g}$$

Rectangular Beams Comparison:

$$\text{concrete area ratios,} \quad \frac{bd}{(bd)_g} = \left(\frac{K_g}{K} \cdot \frac{R.\ M.}{(R.\ M.)_g}\right)^{2/3}$$

$$\text{steel ratios,} \quad \frac{A_s}{A_{sg}} = \frac{bd}{(bd)_g} \cdot \frac{p}{p_g}$$

Rectangular beam comparisons given in section C of Table 7 show area requirements for "C"-Haydite concrete of 85 to 89 per cent with corresponding steel requirements of 101 to 106 per cent, and area requirements for All-Haydite concrete of 74 to 79 per cent, with steel requirements of 103 to 110 per cent, as referred to gravel concrete requirements.

Having obtained the reduced depths shown in Table 7 a further reduction of required resisting moment (due to this decrease in dead load) might be applied thus effecting a further slight reduction of all concrete and steel areas for Haydite concretes.

T-Beams and Beams With Compressive Reinforcement: For a comparison of T-beams of different concretes, since the depth is usually assumed or limited by shear or architectural considerations, only beams of the same stem size will be compared. In general the decrease in bending moment due to reduced dead load for Haydite concretes will be somewhat greater than the decrease in values of j, resulting in a slight saving in steel. A single illustration is given in Table 8 for the design at the center of a T-beam, the problem being taken from "Design and Cost Data for the Building Code," Arthur R. Lord, Proc. A. C. I., Volume 24, 1928, p. 546, problem 2.

In Haydite beams of the same size as gravel the efficiency of compressive steel is increased due to two causes, greater values of n and larger proportions of f_c to be multiplied by these values of n in determining the ability to develop compressive stress in the steel. The larger proportions of f_c result from increased values of k for Haydite concretes and in quantity will depend upon d when the distance from the compression surface to the compression steel is constant.

Shear and Bond: As a result of beam and pull-out tests* to determine bond values and beam tests* to determine diagonal tension resistance of concretes of gravel, "C"-Haydite, and All-Haydite, it was concluded that the same working stresses may be applied to all three concretes for shear and bond.

Deflection: While relative deflections of homogeneous beams of constant size and span will be inversely proportional to their

*Proc. A. S. T. M., Vol. 30, Part II, 1930. "Tests of Plain and Reinforced Haydite Concrete."

E values the same will not be true of non-homogeneous beams of reinforced concrete. This is apparent from a study of Maney's equation† which gives deflection, D, as a function of the separate deformations of the steel fiber, ϵ_s, and the concrete fiber, ϵ_c,

$$D = K \frac{l^2}{d} (\epsilon_s + \epsilon_c)$$

Tests show that beams made with gravel, "C"-Haydite and All-Haydite concrete having relative values of E of 1.00, 0.75 and 0.55, developed relative deflections under a given load of 1.00, 1.15 and 1.30, respectively. This is readily understood by reference to the formula, in which the concrete deformation increases as E decreases, while the steel deformation is only slightly affected by variations in the stiffness of the concrete.

Column Design: In applying a column formula of the type $\frac{P}{A} = f_c [1 + (n - 1) p]$ it is obvious that an increase in n for a constant value of f_c and p would result in increasing the working load and that the higher the percentage p the greater would be the increase in working load. A reinforced concrete column made of Haydite concrete of a given strength can not be expected to carry a greater ultimate load than a similar gravel concrete column, identically reinforced. It is apparent that this type of formula embodying n will not apply to a series of concretes having widely differing values of n for identical strengths. Tests of columns of gravel concrete, "C"-Haydite concrete, and All-Haydite concrete covering plain columns, tied columns having 1.5 per cent and 4 per cent longitudinal steel, and spirally reinforced columns having 1 per cent spiral and 1.5 and 4 per cent longitudinal steel have shown that approximately the same relationships may be expected between load carried, ultimate concrete strength and yield point of reinforcement for all three kinds of concrete regardless of the values of E.

In view of the above considerations it seems advisable in the design of axially loaded Haydite columns to make a simple substitution of concretes, taking no account of a reduction in E, and making only such reduction in dead load as the substitution permits. The above equation indicates a distribution in stress

†Proc. A. S. T. M., Vol. XIV, Part II, 1914. "Relation between Deformation and Deflection in Reinforced Concrete Beams." by G. A. Maney.

between the concrete and the steel at working loads which has little real significance. For cases of eccentrically loaded columns in which the bending moment induced results from a rigid connection with a girder or slab, the low modulus of elasticity of the column may be of considerable advantage. As recently noted by Prof. Hardy Cross, when a heavy stiff girder is supported by relatively light columns, the bending moment induced in the column varies almost directly with its stiffness. Such a column may be difficult to design, since any attempt to increase the resisting moment is likely to increase the stiffness and consequent bending moment. A gravel concrete girder supported on Haydite concrete columns might thus represent a logical and sensible design.

SUMMARY

The principal conclusions to be drawn from the foregoing discussion may be summarized as follows:

The relation between compressive strength and water-cement ratio of Haydite concrete does not differ greatly from that for gravel concrete, all test results falling within a narrow zone as shown in Fig. 2. Concretes made with initially moist Haydite were consistently a little stronger than those made with dry Haydite aggregates. Due to their gradation and surface texture, Haydite aggregates in general required a larger water-cement ratio than gravel aggregates to produce a desired workability with a given mix, as indicated by slump and flow tests.

The determination of the water-cement ratio involves an accurate correction for the amount of absorbed moisture. The total absorption of moisture in a given period varies with the initial moisture condition of the Haydite aggregate, and is greater if the material is initially moist than if it is dry.

It is recommended that to secure workability the proportion by volume of coarse Haydite, of the sizes described herein, shall not exceed 55 per cent of the total aggregate. With this proportion, the unit weight of the usual range of structural concretes will be 115 to 120 lb. per cu. ft. for "C"-Haydite concrete and 95 to 100 lb. per cu. ft. for All-Haydite concrete.

The modulus of elasticity of "C"-Haydite concrete is about 75

per cent and that of All-Haydite concrete about 55 per cent, of that for gravel concrete.

With regard to the design of reinforced slabs and beams, there are two features of Haydite concrete that are important, the lightness in weight and the low modulus of elasticity. The first will permit considerable reductions in dead load over ordinary concrete, thus permitting a reduction in size of members or an increase in span, as well as decreasing loads on columns and footings.

The effect of low modulus of elasticity in a reinforced concrete beam or slab is to lower the neutral axis and to require a higher percentage of steel for balanced reinforcement. However, the depth of member may be decreased so that the saving in concrete quantities will offset the increase in steel requirements.

Combining the effects of light weight and low modulus of elasticity and taking advantage of possible reduction in slab depth, it is found that the substitution of "C"-Haydite for gravel concrete will permit a decrease of 12 to 9 per cent of concrete with an increase of 5 to 8 per cent of steel. With All-Haydite concrete there may be 20 to 15 per cent reduction in concrete with 11 to 17 per cent increase in steel. In rectangular beam design the conditions are even more favorable to the use of Haydite concrete.

The working stresses for bond and diagonal tension apparently may be taken as the same percentage of the compressive strength as is usually recommended for ordinary concrete.

The values of modulus of elasticity found for gravel concrete do not agree particularly well with the design values specified by the A. C. I. Joint Building Code, except at strengths of 3500 to 3750 lb. per sq. in. Use of the Code formula, modified by the introduction of 75 and 55 per cent for "C"-Haydite and All-Haydite concretes will produce considerable error for concretes of very high or very low strengths.

Despite the implications of the current column formulas, such as that of the Joint Building Code, the low modulus of elasticity should not be used to justify any increase in working stresses in Haydite columns over those for gravel concrete. Using concrete

of equal compressive strength, equal ultimate column strengths will result. The smaller stiffness of Haydite columns may be of advantage in decreasing column moments in rigid frames and like structures.

Because of the variation of construction costs in different localities, no attempt has been made to carry the foregoing studies through to the ultimate cost of any structure. However enough has been given to indicate the variation in quantities to be expected in certain common structural members. Other less tangible features of the Haydite concrete structure may lie in the possibility of increased building heights, the use of cheaper types of footings, the possibility of greater panel sizes, and the utilization of insulating properties of the material. The saving of weight in a structure such as in a bridge floor or in a longspan roof is of very obvious advantage. Both the properties of the material and its economy in design remain to be explored more fully.

TABLE 1
PROPERTIES OF HAYDITE AGGREGATES

Property	Fine ("A") Haydite	Coarse ("C") Haydite
Unit Weight		
Dry, Rodded, A. S. T. M. Method	60—64	45—49
Dry, Loose measure	50—56	41—45
Moist, Loose, as received	51	46
Moisture Content as received		
Per cent, by weight	2.9—27.0	3.3—7.6
Fineness modulus	2.3—3.0	5.9—6.3
Apparent specific gravity	.....	1.25—1.32

TABLE 2

DATA OF COMPRESSION TESTS OF HAYDITE CONCRETE

Proportions by loose dry volume.
Dry aggregates used.
Water allowed for absorption: Sand, 1 per cent; Fine Haydite, 14 per cent; Coarse Haydite, 7 per cent.
Quantities required per cubic yard of concrete based on fresh concrete.
No allowance has been made for settlement and waste.
All values given are the average of three tests.

Aggregates	Mix	Water Cement Ratio by Vol.	Slump inches	28-Day Cylinders		Quantities Req'd per cu. yd. of Concrete		
				Compressive Strength lb. per sq. in.	Initial Modulus of Elasticity lb. per sq. in.	Cement bbl.	Sand or Fine Haydite cu. yd.	Coarse Haydite cu. yd.
Sand and Coarse Haydite	1:1½:2½	0.77	6.2	4300	2,610,000	1.83	0.41	0.68
		0.87	8.7	3810	2,440,000	1.79	0.40	0.66
		0.97	9.7	2940	2,370,000	1.75	0.39	0.65
	1:2 :2	0.76	3.1	4370	3,010,000	1.81	0.54	0.54
		0.86	8.5	3960	2,780,000	1.78	0.53	0.53
		0.96	10.2	3190	2,600,000	1.73	0.51	0.51
	1:2 :3	0.89	4.6	3640	2,600,000	1.51	0.45	0.67
		0.99	8.3	3110	2,370,000	1.50	0.44	0.67
		1.09	8.6	2530	2,150,000	1.47	0.44	0.65
	1:2½:2½	0.87	2.6	3490	2,680,000	1.50	0.56	0.56
		0.97	7.8	3030	2,530,000	1.48	0.55	0.55
		1.07	8.5	2700	2,310,000	1.43	0.53	0.53
	1:2½:3½	1.10	4.6	2530	2,250,000	1.29	0.48	0.67
		1.20	6.2	2050	2,210,000	1.26	0.46	0.65
		1.30	7.6	1850	2,000,000	1.24	0.46	0.64
	1:3 :3	1.09	3.1	2620	2,450,000	1.27	0.56	0.56
		1.19	5.1	2100	2,220,000	1.25	0.56	0.56
		1.29	6.9	1920	2,250,000	1.24	0.55	0.55
Fine and Coarse Haydite	1:1½:2½	0.86	5.4	3700	2,010,000	1.86	0.41	0.69
		0.96	6.6	3060	1,860,000	1.79	0.40	0.66
		1.06	9.6	2440	1,800,000	1.75	0.39	0.65
	1:2 :2	0.88	5.5	3470	1,950,000	1.83	0.54	0.54
		0.98	7.5	2890	1,670,000	1.77	0.52	0.52
		1.08	9.9	2490	1,770,000	1.73	0.51	0.51
	1:2 :3	1.01	1.9	2530	1,820,000	1.53	0.45	0.68
		1.11	5.3	2300	1,730,000	1.50	0.44	0.67
		1.21	8.4	1920	1,670,000	1.47	0.44	0.65
	1:2½:2½	1.03	1.7	2620	1,850,000	1.51	0.56	0.56
		1.13	5.4	2310	1,810,000	1.50	0.56	0.56
		1.23	7.7	2060	1,630,000	1.46	0.54	0.54
	1:2½:3½	1.25	1.0	1580	1,330,000	1.30	0.48	0.68
		1.35	7.4	1680	1,620,000	1.28	0.48	0.67
		1.45	7.6	1310	1,540,000	1.24	0.46	0.64
	1:3 :3	1.27	2.7	1760	1,690,000	1.29	0.57	0.57
		1.37	5.3	1620	1,310,000	1.28	0.57	0.57
		1.47	6.7	1280	1,570,000	1.23	0.55	0.55

TABLE 3

EFFECT OF LIGHTNESS IN WEIGHT

Percentage of Total Load to be Carried

Kind of Concrete	Relative Unit Weights of Concrete	Dead Load—Percentage of Total Load				
		60	50	40	30	20
Gravel	100	100	100	100	100	100
C-Haydite	80	88	90	92	94	96
All-Haydite	67	80	83	87	90	93

TABLE 4

COMPARATIVE DESIGN OF RECTANGULAR BEAMS AND SLABS BASED UPON EXPERIMENTAL VALUES OF E

Balanced Reinforcement, $f_s = 20{,}000$ lb. per sq. in., $f_c = 0.40\,f'_c$.

Sec.	Property	Gravel Concrete				"C"-Haydite				All-Haydite			
	f'_c	2000	2500	3000	3750	2000	2500	3000	3750	2000	2500	3000	3750
	f_s	800	1000	1200	1500	800	1000	1200	1500	800	1000	1200	1500
A	n	10.1	9.4	8.8	8.0	13.4	12.7	11.6	11.0	18.4	17.1	16.0	14.5
	k	0.288	0.319	0.346	0.375	0.348	0.388	0.417	0.452	0.423	0.461	0.490	0.520
	j	0.904	0.894	0.885	0.875	0.884	0.871	0.861	0.849	0.859	0.846	0.837	0.827
	p	0.0058	0.0080	0.0104	0.0140	0.0070	0.0097	0.0125	0.0169	0.0085	0.0115	0.0147	0.0195
	K	104	143	184	246	123	169	216	288	145	195	245	322
	Slab Comparison Based upon Constant Resisting Moment. b constant, d varies												
B	$\frac{d}{d_g}$ percent	100	100	100	100	92	92	92	91	84.5	86	87	87.5
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	111	111	110.5	110	123.5	124.0	122.5	121.5
	Slab and Rect. Beam Comparison Based upon Constant b and d for All Concretes.												
C	$\frac{K}{K_g}$ percent	100	100	100	100	118	118	117	117	139	136	133	131
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	121	121	120	121	146	144	141	139
	Rectangular Beam Comparison Based upon Constant Resisting Moment and upon Proportional b and d for Haydites and Gravel												
D	$\frac{bd}{(bd)_g}$ percent	100	100	100	100	89.0	89.5	90.0	90.0	80.0	80.5	82.5	83.5
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	107	108	108	109	117	116	117	116

Note: Subscript g denotes gravel concrete.

TABLE 5

COMPARATIVE DESIGN OF RECTANGULAR BEAMS AND SLABS BASED UPON VALUE OF K FROM A. C. I. CODE

$f_s = 20{,}000$ lb. per sq. in., $f_c = 0.40\,f'_c$.

Balanced Reinforcement

Sec.	Property	Gravel Concrete $E_g = 1000\,f'_c$				"C"-Haydite $E_h = 750\,f'_c$				All-Haydite $E_a = 550\,f'_c$			
A	f'_c	2000	2500	3000	3750	2000	2500	3000	3750	2000	2500	3000	3750
	f_c	800	1000	1200	1500	800	1000	1200	1500	800	1000	1200	1500
	n	15	12	10	8	20	16	13.3	10.7	27	21.8	18.2	14.5
	k	0.375	0.375	0.375	0.375	0.445	0.445	0.445	0.445	0.521	0.521	0.521	0.521
	j	0.875	0.875	0.875	0.875	0.852	0.852	0.852	0.852	0.826	0.826	0.826	0.826
	p	0.0075	0.0094	0.0112	0.0140	0.0089	0.0111	0.0133	0.0167	0.0104	0.0130	0.0156	0.0195
	K	131	164	197	246	151	189	227	284	172	215	258	323
	Slab Comparison Based upon Constant Resisting Moment. b constant, d varies.												
B	$\frac{d}{d_g}$ percent	100	100	100	100	93	93	93	93	87.5	87.5	87.5	87.5
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	111	111	111	111	121.5	121.5	121.5	121.5
	Slab and Rect. Beam Comparison Based upon Constant b and d for all Concretes												
C	$\frac{K}{K_g}$ percent	100	100	100	100	115	115	115	115	131	131	131	131
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	119	119	119	119	139	139	139	139
	Rectangular Beam Comparison Based upon Constant Resisting Moment and upon Proportional b and d for Haydite and Gravel Concretes												
D	$\frac{bd}{(bd)_g}$ percent	100	100	100	100	91	91	91	91	83	83	83	83
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	108	108	108	108	115	115	115	115

Note: Subscript g denotes gravel concrete.

TABLE 6

COMPARATIVE DESIGN OF RECTANGULAR BEAMS AND SLABS BASED UPON CONSTANT VALUE OF R

Balanced Reinforcement, $f_s = 20{,}000$ lb. per sq. in., $f_c = 0.40\,f'_c$.

Sec.	Property	Gravel Concrete $E_g = 3{,}400{,}000$ $n_g = 8.8$				"C"-Haydite $E_h = 2{,}500{,}000$ $n_h = 12.0$				All Haydite $E_a = 1{,}900{,}000$ $n_a = 15.8$			
	f'_c	2000	2500	3000	3750	2000	2500	3000	3750	2000	2500	3000	3750
	f_c	800	1000	1200	1500	800	1000	1200	1500	800	1000	1200	1500
A	k	0.260	0.306	0.345	0.398	0.325	0.375	0.419	0.474	0.388	0.442	0.487	0.543
	j	0.913	0.898	0.885	0.867	0.892	0.875	0.860	0.842	0.871	0.853	0.838	0.819
	p	0.0052	0.0076	0.0103	0.0149	0.0065	0.0094	0.0126	0.0178	0.0078	0.0110	0.0146	0.0204
	K	95	137	183	258	116	164	216	299	135	188	245	333
	Slab Comparison Based upon Constant Resisting Moment. b constant, d varies												
B	$\frac{bd}{(bd)_g}$ percent	100	100	100	100	90.5	91.5	92.0	93.0	84.0	85.5	86.5	88.0
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	113.0	113.5	112.0	111.5	126.0	124.0	123.0	120.5
	Slab and Rect. Beam Comparison Based upon Constant b and d for all concretes.												
C	$\frac{K}{K_g}$ percent	100	100	100	100	122	120	118	116	142	137	134	129
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	125	124	122	120	150	145	152	137
	Rectangular Beam Comparison Based upon Constant Resisting Moment and upon b and d for Haydites proportional to b and d for gravel.												
D	$\frac{bd}{(bd)_g}$ percent	100	100	100	100	87.5	89.0	89.5	90.5	79.0	81.0	82.0	84.5
	$\frac{A_s}{A_{sg}}$ percent	100	100	100	100	109	110	109	108	118	117	116	115

Note: Subscript g denotes gravel concrete.

TABLE 7

EFFECT OF LIGHTNESS IN WEIGHT AND LOW VALUE OF E

Comparative design of Slabs and Rectangular Beams Based upon Proportional A. C. I. Code Values of E.

Balanced Reinforcement, $f_s = 20{,}000$ lb. per sq. in., $f_c = 0.40\,f'_c$.

All values of f'_c included.

For values of n, k, j, p, and K see Table 5.

Sec.	Property	Gravel Concrete $E_g = 1000\,f'_c$				"C"-Haydite Concrete $E_h = 750\,f'_c$				All-Haydite Concrete $E_a = 550\,f'_c$			
A	$\frac{\text{Dead Load}}{\text{Total Load}}$, per cent	50	40	30	20	50	40	30	20	50	40	30	20
	$\frac{R.\,M.}{(R.\,M.)_g}$, per cent (See Table 3)	100	100	100	100	90	92	94	96	83	87	90	93
	Slab Comparison Based upon Reduced Resisting Moment Req'd. b constant, d varies.												
B	$\frac{d}{d_g}$, per cent	100	100	100	100	88	89	90	91	80	81	83	85
	$\frac{A_s}{A_{sg}}$, per cent	100	100	100	100	105	106	107	108	111	113	115	117
	Rectangular Beam Comparison Based upon Reduced Resisting Moment. Proportionally Reduced b and d.												
C	$\frac{bd}{(bd)_g}$, per cent	100	100	100	100	85	86	87	89	74	76	78	79
	$\frac{A_s}{A_{sg}}$, per cent	100	100	100	100	101	102	104	106	103	106	108	110

TABLE 8

COMPARATIVE DESIGN AT CENTER OF T-BEAM

Slab, 4-in. total thickness.
Stem, 12 x 16 inches.
Beam spacing, 6 ft. centers.
f'_c = 3000 lb. per sq. in.
f_s = 20,000 lb. per sq. in.

Property	Kind of Concrete		
	Gravel	C-Haydite	All-Haydite
Total load—lb. per sq. ft.	300	290	285
Slab load—per lin. ft. of bm.	1800	1740	1710
Weight of stem	150	120	100
Total load, W—lin. ft. of bm.	1950	1860	1810
W/W_g, per cent	100	95	93
B. M., $\frac{WL}{16}$ in. lb.	845,000	806,000	784,000
j	0.884	0.875	0.870
j/j_g, per cent	100	99	98.5
A_s, sq. in.	3.52	3.41	3.34
A_s/A_{sg}, per cent	100	97	95

Readers are referred to the JOURNAL *for February, 1931, for discussion which may develop. Such discussion should reach the Secretary by January 1, 1931.*

Blast Furnace Slag as Concrete Aggregate

Report of Committee 201, Aggregate Specifications

Former Institute Committee E-5, Aggregates, assigned its subcommittee on Slag, H. J. Love, Chairman, to report a summary of available information on Blast Furnace Slag as Concrete Aggregate. The report here presented, as the result of that assignment, has been approved by the successor Committee 201, Aggregate Specifications, H. F. Clemmer, Chairman, and is here offered for the information of Institute members and others and discussion invited.—Editor

1. Definition of blast furnace slag

"Blast furnace slag is the non-metallic product, consisting essentially of silicates and alumino-silicates of lime, which is developed simultaneously with iron in the blast furnace." (Proc., Amer. Con. Inst., page 524, 1925).

2. Introduction

The technical committees of practically all the national organizations interested in construction materials have approved the use of slag aggregate in specifications or reports, including the following:

Amer. Concrete Institute; Amer. Soc. for Testing Materials; Amer. Railway Engineering Assn.; Amer. Soc. for Municipal Improvements; Associated Tile Manufacturers; National Paving Brick Manuf. Assn.; Portland Cement Assn.; Asphalt Institute; Amer. Assn. of State Highway Officials; Federal Specifications Board; U. S. Bureau of Roads (Dept. of Agriculture); U. S. Bureau of Standards (Dept. of Commerce); State Highway Departments of Alabama, Delaware, Dist. of Columbia, Florida, Georgia, Kentucky, Maryland, Mississippi, Missouri, New York, New Hamsphire, South Carolina, Ohio, Pennsylvania, Utah and West Virginia.

Although the tonnage of slag used is only about 4 per cent of the estimated total of all aggregates, this amount is confined almost exclusively to the large centers of population having steel mills, so that the use of slag becomes more important than is

indicated by its comparative tonnage. With this in mind, the Committee has made first-hand investigations of the properties and uses of blast furnace slag as revealed in (a) Actual service in the field and (b) Test data and technical literature. The latter have been made available to the Committee by the National Slag Association through its symposiums, which have been issued regularly during the last two years for the benefit of national technical societies engaged in formulating specifications.

On one inspection trip, 115 miles of slag concrete pavement were inspected, in addition to slag concrete factory buildings, office buildings, residences, bridges, water tanks, boiler stacks and fences. The latter item, fences, included the mile-long cast-in-place fence along the property of the Carnegie Steel Co., Youngstown, O., which has been standing for 13 years. Eight bridges were inspected on this trip, including the 16-year old North Howard bridge at Akron, O., the 15-year Lake Milton bridge west of Youngstown, O., the 14-year West Summit St. bridge at Warren, O., the North Hill Viaduct in Akron, and Lanternman's Falls bridge in Youngstown.

The interest shown in slag aggregate is evinced by papers published in the Proceedings of the American Concrete Institute:

"Slag as Concrete Aggregate," by Sanford E. Thompson, Vol. 13, p. 107.
"Tests of Slag as the Coarse Aggregate in Concrete," by P. J. Freeman, Vol. 14, p. 95.
"Fire Tests of Concrete Columns," by Walter A. Hull, Vol. 14, p. 138.
"Fire Tests of Concrete Columns," by Walter A. Hull, Vol. 16, p. 20.
"Flexural Strength of Plain Concrete," by Duff A. Abrams, Vol. 18, p. 20.
"Report of Fire Resistance of Concrete Building Units," by A. C. I. Committee P-5, Vol. 19, p. 331.
"Proportioning Concrete Materials," by George W. Hutchinson, Vol. 21, p. 148.
"Concrete Pavement Design," by L. W. Teller and J. T. Pauls, Vol. 22, p. 314.
"Tests of Retempered Concrete," by H. F. Gonnerman and P. M. Woodworth, Vol. 25, p. 344.

In addition to these papers, the Institute recognized slag aggregate in the following specifications:

"Proposed Specifications for Sidewalks and Floors," 1919.
"Standard Building Regulations for Reinforced Concrete," 1920.
"Standard Specifications for Monolithic Concrete Sewers and Reinforced Concrete Pipe Sewers," 1920.

"Standard Specification for Cement Concrete Pavements," 1924, revised in 1925.

"Tentative Purchase Specifications for Concrete Aggregates," 1929.

3. Processing blast furnace slag

The processing of slag really begins in the blast furnace, where the iron and slag are produced simultaneously. Layers of coke, flux stone and ore are placed in the furnace through an opening in the top, and the mass subjected to a blast of hot air. During combustion of the coke, the gangue or dross of the ore separates from the metallic iron and combines with the flux stone, and it is this combination, along with certain non-combustible material in the coke, which forms blast furnace slag. At the base of the furnace the molten slag and iron automatically separate due to difference in specific gravity, the slag floating on the iron. The slag is drawn off between iron flushes through the "slag notch" in the side of the furnace above the level of the molten iron. The iron is drawn off through a lower hole (the "iron notch") on the other side of the furnace, followed by any slag which has accumulated since the last slag flush.

Methods of Cooling

Slags are of two classes with regard to method of handling on leaving the furnace:

1—Slag which is brought from molten to solid form entirely through the agency of atmospheric air, known as air-cooled blast furnace slag.

2—Slag which is changed from molten to solid form by means of water or other rapid-cooling agency, known as granulated slag.

Although by far the greater portion of commercialized slag is in the air-cooled form, granulated slag finds an extensive use for the following purposes:

Fills, including backfilling.
Subgrade soil corrective in pavement construction.
Sub-base (blanket) course under all types of pavement.
Bedding course under brick pavement.
Granulated slag roads.
Aggregate in concrete products of all kinds.
Soil corrective in agriculture.
Raw material in manufacture of portland cement.

In Europe slag has been granulated by water, steam, and air under pressure, but American practice invariably makes use of

water. The molten slag is conducted in runners to a pit containing a small amount of water, where it may be struck by a stream of water under pressure, or may be granulated merely by falling into the pit. It can then be removed immediately with grab-buckets. Except for chemical composition, granulated slag is an entirely different product from air-cooled slag, being highly porous, easily crumbled in the hand, and occurring in sharp grains. It is gray or yellow in color. Except for concrete products, it is little used as concrete aggregate.

Methods of Disposal

Commercial slag aggregate for concrete is produced from air-cooled slag. From the furnace the molten slag may follow one of two courses: It may flow through runners direct to small pits alongside the furnace (known as the pit system of disposal), or it may be poured into large ladles mounted on standard railway trucks and conveyed to a more distant point for disposal. The latter operation, in turn, may take one of two methods:

1—The slag may be poured from the ladles into large, well-defined pits served by permanently-located pouring and loading tracks, from which it is regularly excavated (known as the modified pit system).

2—The slag may be poured from the ladles over a large plot of land with no very definite attempt to control width or depth of the solid slag so formed (known as the bank system).

Modern practice follows for the most part either the pit or modified pit system, each of which has its peculiar advantages. The pit system calls for a small percentage of the area demanded by the modified pit system, but that area must be alongside the furnace, which is not always feasible. The modified pit system, covering a larger area, has the advantage of providing greater storage facilities for the slag, so that the crushing and screening plant need not be running continuously as with the pit system. The bank system calls for large areas of land and has other disadvantages making for its disuse.

The molten slag is poured into the pits in a thin layer, which brings about a rapid drop in temperature and the solidification of the material. Succeeding layers retain some heat in the mass and a tempering action takes place, resulting in a hard, tough

product suitable for processing into concrete aggregate. When one pit has been filled by successive pourings, the filling of another begins, while a power shovel may enter the full pit and excavate the solidified slag. Where the pit system is in use, the shovel follows the filling of the pit very closely, but in large modified-pit layouts six months may elapse between filling and excavating. The time the slag lies in pits before use depends on the size of the pits and the demand for the product. At one time it was thought advisable to specify that the slag lie in the pits for a definite period of "aging," but tests and observations[15]* have shown this to be unnecessary, and now there are excavated and used annually in Ohio alone 1,250,000 tons of slag less than two weeks old. The total production for commercial purposes throughout the United States approximates 10,000,000 tons annually, about thirty per cent of which is used as concrete aggregate.

Crushing and Screening Operations

The process of cooling in layers provides planes in the slag mass which assist materially in excavation, and blasting is very seldom resorted to. The slag as excavated is loaded into dump cars and carried to the crushing and screening plant, where it passes through the processes typical of a plant preparing crushed aggregate for the market. There is one exception, however,—the slag is passed over magnetic separators during the operation in order to remove any small pieces of metallic iron carried over into the slag at the furnace. These are returned to the steel companies and reclaimed. After the screening operation has been completed, the slag is chuted to bins from which railroad cars or motor trucks may be filled.

4. Physical and chemical characteristics of slag

Air-cooled blast furnace slag as produced for commercial purposes is a rough, angular aggregate varying in color from light to dark gray, depending upon the character of the materials charged to the furnace. The roughness is due to its cellular structure, and the degree of roughness varies as the cells are large or small, many or few. These cells are formed by gases occluded in the slag at time of cooling, and are generally non-communicating; hence the term "cellular" or "vesicular" is more applicable than the term "porous." As excavated from the pit or bank,

*All references are to the bibliography at end of report.

slag breaks into roughly cubical pieces containing practically no flat pieces or slivers. This angularity, combined with its rough surface texture, gives slag a larger surface area per unit of volume than is usually found in concrete aggregates.

When fresh, there is a perceptible odor from blast furnace slag due to the small amount of sulphur compounds which it contains (1.00-1.75 per cent), but later this almost entirely disappears. Since it has passed through the high temperatures of the blast furnace, slag is a particularly clean material, and it is dug from pits in which nothing but slag is placed. It is also clean from the standpoint of adherent dust-coating, since this is readily removed during the screening operation.

Specific Gravity

The apparent specific gravity of air-cooled blast furnace slag as determined by the standard method averages about 2.25, although samples will be found ranging from 1.80 to 2.80 due to the cellular structure of the material. The true specific gravity of the solid material is fairly constant between 3.00 and 3.10.

Weight per Cubic Foot

The difference in specific gravity of various pieces of slag inevitably affects the weight of the aggregate per cubic foot,—if the unit of volume contains a large percentage of either light or heavy pieces, the weight may vary from 65 to 100 lb. per cu. ft. in the concrete aggregate sizes. The higher weights are relatively rare and represent only a very small per cent of the total tonnage. In general, the highest weight in the concrete aggregate sizes is about 85 lb. The foregoing weight values are based on the aggregate compacted in a dry condition; if the material is weighed loose, the values will be approximately 10 lb. per cu. ft. lower.

Voids and Absorption

Void determinations by the water displacement method show a void content of 40-45 per cent (average 42 per cent) in slag sized for concrete aggregate. If the determination is made by calculation from the specific gravity and weight per cubic foot, the result will be approximately the same if the specific gravity has been based on a representative sample. The presence of light or heavy pieces in practically all blast furnace slags makes

most specific gravity determinations of doubtful value and also greatly affects the absorption determination, since a few pieces of such slag will affect the absorption appreciably. Furthermore, the small sample chosen for absorption and specific gravity determinations may contain a much larger percentage of light or heavy pieces than the stockpile, bin or car of which it is supposed to be representative. Absorption tests show an average of about 4 per cent by weight with a high and low range of 25.0 to 0.25 per cent, with the great majority lying within the field of 2-4½ per cent absorption. Although these average figures appear somewhat high in comparison with other aggregates, the actual amount of water absorbed may be no greater than that indicated by a lower percentage on other aggregates, due to the latter having specific gravities averaging 20 per cent higher than slag. For example, a slag of specific gravity 2.21 and an absorption by weight of 6 per cent has the same absorption *by volume* as an aggregate of specific gravity 2.65 and an absorption by weight of 5 per cent.

The absorption which takes place in the first 30 minutes is usually that considered in proportioning slag concrete, and allowance must be made for this amount if the mixing water is to be kept under control.

Hardness and Toughness

Hardness and toughness factors have been found meaningless when applied to slag aggregate, and are no longer required in specifications.

Resistance to Abrasion

Testing slag for resistance to abrasion in the Deval machine is subject to the same difficulties as the specific gravity and absorption determinations. The small sample may contain many more of the light or heavy pieces than the pile from which it was taken, and these pieces will materially affect the test results. It is further believed that neither stone nor slag is adapted to such a test, since the sharp edges are rapidly broken off and appear as "loss by abrasion," even though such breakage represents a large part of that which occurs throughout the duration of the test. That this actually happens has been proven by tests on slag,[1] in which the sharp edges were first worn off in the machine, and the

material then subjected to the standard Deval test. The results showed that a slag which averaged 13.2 per cent loss in the natural state averaged only 8.2 per cent loss with the sharp edges removed. The standard Deval test, which is used only on large-sized pieces of aggregate, gives test results on slag varying from 2½—43 per cent, but the average loss lies within the limit of 12—16 per cent.

The modified Deval abrasion test, in which steel balls are introduced as an abrasive charge, is used in Ohio for testing the concrete aggregate sizes. The wear is proportionately greater, averaging about 25 per cent loss with a range of 15-38 per cent.

The abrasion factor as a specification requirement on slag is being eliminated from most specifications, following the path of hardness and toughness factors. The inaccuracy of the Deval abrasion test as applied to slag is strikingly brought out in data recently presented to the American Association of State Highway Officials. These data were obtained by 17 well known laboratories coöperating in tests of slags from four different sources. In order to insure uniformity of the samples, they were selected from each source by A. S. Rea, Chief Engineer of Tests, Ohio Highway Dept., and shipped to the respective laboratories for testing. The abrasion tests were run according to the Standard Deval method (A. S. T. M. Serial Designation D 2-26). When the results were reported, a decided variation among laboratories was evident. In the following table is summarized (a) The maximum, minimum and average of all laboratories for each slag, (b) The maximum variation from the average shown by any one laboratory, and (c) The mean variation from the average. The latter was arrived at by totalling the individual variations from the average, and dividing the sum by seventeen.

Slag	Abrasion Loss			Variations from Average Per Cent	
	Max.	Min.	Ave.	Maximum	Mean
A	23.0	9.1	13.6	69	15
B	21.5	7.8	13.2	62	14
C	18.3	5.1	12.9	60	15
D	6.6	1.0	4.7	78	18

These large variations from the average were not confined to any one laboratory; in general variations of 10 per cent or more

were obtained with all four slags in most of the laboratories.

To determine whether abrasion test results could be duplicated in the same laboratory, seven of the 17 laboratories were asked to run check samples. These consisted of samples designated Slags E, F, G and H, which were selected by Mr. Rea at the same time and from the same source as Slags A, B, C and D, respectively, although this fact was not known to the cooperating laboratories.

Considered as a separate series of tests, the results obtained on Slags E, F, G and H by the seven laboratories show equally as much variation between laboratories as did Slags A, B, C, and D. Tabulated in the same manner as the results from the latter, Slags E, F, G and H showed the following variations:

Slag	Abrasion Loss			Variations from Average Per Cent	
	Max.	Min.	Ave.	Maximum	Mean
E	14.5	3.9	11.7	67	22
F	15.1	9.8	12.6	22	12
G	13.7	4.1	11.4	64	21
H	6.0	0.4	4.0	90	30

In view of the foregoing, it is evident that the Standard Deval abrasion test will not develop concordant results on uniform samples of blast furnace slag, and therefore should be omitted from specifications for slag aggregate.

Crushing Strength

The crushing resistance of slag is about that of the more common aggregates,—approximately 9,000-12,000 lb. per sq. in. —but this factor is of minor importance since it is well above the strength required in concrete.

Cementation Value

The cementation value of blast furnace slag, as measured by the cementation test (described in U. S. Dept. of Agriculture Bulletin 347) varies according to the chemical composition, slags containing a large percentage of calcium oxide having a greater cementing value. Thus there is record of cementing values on blast furnace slag from 3 to 600, indicating the number of blows withstood by a cylinder made of a mixture of finely ground slag and water, the weight of the hammer being 1 kgm. and the height of fall 1 cm.

Melting Point

With regard to the melting point of slag, tests have shown it to be fluid between 2300-2600° F., viscous at 2200° F., and solid at 2100° F. or lower.

Chemical Composition

Chemically, blast furnace slag is made up of calcium oxide (CaO), alumina (Al_2O_3), silica (SiO_2), and magnesia (MgO); there are also small quantities of iron oxide (FeO), manganese oxide (MnO), and sulphur compounds. The chemical composition is entirely dependent upon the nature of the materials charged to the furnace,—the lime and magnesia in the flux stone, the alumina and silica in coke and ore. Although this brings about a difference in chemical analysis for slags from different sources, the slag from any one source maintains a marked degree of uniformity. Thus, monthly analyses of slags from 24 sources in Ohio, Pennsylvania and Kentucky over a 12-month period in 1927 showed mean variations from the average as indicated in the following tabulation:

CONSTITUENT	AVERAGE OF ALL TESTS	MEAN VARIATION FROM AVERAGE
	Per Cent	Per Cent
SiO_2	36.44	2.38
Al_2O_3	12.73	2.13
CaO	41.28	1.83
MgO	6.50	1.20

The relatively high variation in magnesia content (1.20 in 6.50) is due to the use of magnesian limestone or dolomite as flux at some furnaces, while others use nothing but limestone. The general range in chemical composition of blast furnace slag is within the following limits:

SiO_2	32–40	Per Cent
Al_2O_3	10–17	"
CaO	30–49	"
MgO	3–14	"
FeO	.5–2	"
Sulphur	1–2	"

Petrographic Composition

Petrographically, slag is composed mainly of silicates, such as di-calcium silicate and calcium alumino-silicate. There have also been found melilite, periclase, spinel, forsterite, pyroxene,

cordierite, mullite, christobilite, tridymite, anorthite, gehlenite, olivine and akermanite.

5. Properties of slag concrete

Weight

The weight of slag concrete varies from 127 to 150 lb. per cu. ft. according to the mix used and the weight of the slag aggregate itself. Rich mixes containing more of the relatively heavy cement and sand naturally weigh more than the leaner mixes. The figure of 135 lb. per cu. ft. may be taken as average for the intermediate mixes (1:2:3, 1:2½:4 etc.) when a medium-weight slag (70-80 lb. per cu. ft. compact) is used as coarse aggregate.

Absorption

The absorption of any concrete is more affected by the mortar, the cement content, the water content, and the density of the concrete than by the type of aggregate used. The average of all available absorption tests on slag concrete show a value of 5.5 per cent by weight. As in the case of absorption determinations on slag aggregate, this value is not as high as it may appear, since any stated weight of water absorbed will show up as a larger percentage of absorption in slag concrete than in other concretes weighing 10-15 lb. per cu. ft. more. Five and one-half per cent absorption in slag concrete corresponds to 5 per cent absorption in the heavier concretes.

Bond

When "bond" is spoken of in connection with concrete, it may mean either of two properties: (a) Adhesion between concrete and reinforcing steel, or (b) Adhesion between mortar and aggregate. Bond of steel with concrete, being almost entirely a function of the mortar, is the same for slag concrete as other concretes.

With respect to adhesion of mortar and aggregate blast furnace slag possesses several advantages. The rough pitted surfaces and the angularity of the fragments each aids the mortar in obtaining a high degree of bond, so that tests on slag concrete very seldom show failure of the bond between mortar and slag. Such a bond is never the weak point in a slag concrete. Quoting Sanford E. Thompson[3] on this subject:

Inspection of the crushed specimens (of slag concrete) where breaks occur through the pieces shows a very strong bond between the mortar and the pieces of slag. While this probably is due in part to the rough nature of the surface of the slag, it is evident from inspection that a chemical action has taken place between the slag and the mortar. This is shown by a circle of a different color around the edges of the sections of slag.

Durability

The durability of slag concrete has been tested in thousands of structures over a period of 50 years, including buildings, machinery foundations, bridges and pavements. The durability of the aggregate itself has been proven by its successful use as ballast, road material and sewage filtering medium, and also by various test methods. The most prominent of the latter are the sodium sulphate test and the freezing and thawing test. Raymond Harsch[4] has reported sodium sulphate tests on slags from 32 sources in the United States, all the samples being unaffected after 5 cycles of the test.

C. C. Hommon[5] selected thirty-seven samples of slag which had been used as sewage filtering media in as many beds throughout the eastern and southern states. Ten pieces from each of these samples were subjected to 20 cycles of the sodium sulphate test. Although the material had been exposed to the effects of sewage and weather for periods varying from 1 to 21 years, this admittedly severe test had little effect on them, as shown in the accompanying table. The four samples which showed any effect whatever were aged respectively 6, 8, 12 and 14 years. The following table, which includes stones and gravel sampled and tested during the same investigation, shows the results of the tests:

AGGREGATE	NUMBER OF PIECES					PIECES UNAFFECTED
	Tested	Checked	Chipped	Split	Crumbled	Per Cent
Slag	340	0	0	0	0	100
Limestone	20	0	0	0	0	100
Granite	30	0	0	0	0	100
Traprock	10	0	0	0	0	100
Slag	30	1	1	1	0	90
Granite	10	0	0	1	0	90
Slag	10	0	0	2	0	80
Feldspar	10	2	0	0	0	80
Gravel	10	0	0	2	0	80

Limestone	10	2	0	2	0	60
Limestone	10	3	0	0	2	50

In tests by George B. Gascoigne[6], six slags from as many sources were subjected to 10 cycles of sodium sulphate, with result that three pieces of slag out of 36 split, but none of the others were affected in any way. In addition, three of the slag samples were carried to 20 cycles; of the 18 pieces tested at 20 cycles, 6 were unaffected, 4 showed checking, 4 splitting and 4 cracking, but none of the pieces crumbled.

The most extensive series of sodium sulphate tests on record has been carried out by Fred Hubbard[7] on slags from 44 sources in Ohio, Pennsylvania, Maryland and Kentucky. Each of the 422 samples tested underwent 5 cycles of sodium sulphate without showing any signs of checking or cracking, representing a total of 4220 separate pieces of slag. In addition, 358 of the samples (3580 pieces) were carried through to 20 cycles. Of these, 3550 remained intact, denoting a remarkable resistance to the severe action of expanding sodium sulphate crystals. The 30 pieces which did not sustain 20 cycles without some breakdown showed a clean splitting off of one or more fragments in practically every case, there being only three pieces in which there was any crumbling of the material. In terms of percentage, this amounts to 0.08 per cent crumbling material—a negligible quantity.

Freezing and thawing tests of slag have been reported by Edward Orton Jr.,[8] showing a loss of only 0.65 per cent after 30 alternations. G. B. Gascoigne's[6] report also includes the results of such tests, carried to 100 cycles on 2-3 in. pieces as shown in the following table:

AGGREGATE	PIECES TESTED		CONDITION FOLLOWING TEST			
	No.	Weight, Gm.	Pieces over 1"		Fines under 1"	
			No.	Weight, Gm.	Weight, Gm.	Per Cent by Wt.
Slag—1	27	3250	28	3168	82	2.5
Slag—2	22	2993	25	2864	129	4.3
Slag—3	39	3320	40	3209	111	3.3
Slag—4	20	3780	29	3594	186	4.9
Slag—5	18	3966	27	3877	89	2.2
Slag—6	25	3147	29	2935	212	6.7

Tests at the U. S. Bureau of Standards[9] included not only freezing and thawing, but boiling and drying, sodium chloride, and sodium sulphate. Each aggregate was from a different source—6 slags, 3 granites, 4 traprocks, 4 sandstones, 7 limestones and 12 gravels. At the time of the last report, 24 cycles of freezing and thawing had been completed on 28 of the 36 aggregates, and 40 cycles of the other three methods on all 36 aggregates. The report states in part:

> Of the types of aggregates used in these tests, the limestones are apparently showing the greatest disintegration. With few exceptions, by far the greater number of pieces of gravel are sound. Granites have not been affected, and only occasional pieces of trap, sandstone and slag have shown signs of breaking up under these tests.

Probably the best test of the durability of any aggregate is its behavior when used as a filtering medium in sewage beds. Here the surface pieces receive every possible temperature extreme, in addition to alternate freezing and thawing, alternate wetting and drying, and the destructive effects of the sewage itself, which is often increased by the presence of industrial wastes such as acid pickle-liquor from steel mills, tannery wastes, etc. Yet the recent survey of C. C. Hommon[5] showed very little disintegration of the slag filtering medium in 37 sewage beds, 16 of which had been in service for 10-21 years. This survey covered all the slag filter beds which could be found in the United States, and particular attention was paid to the three possible forms of disintegration—splitting, crumbling and flaking. At 29 of the plants, crumbling and flaking were either not present or it was necessary to examine very closely to find them. At 26 plants the same condition obtained with regard to splitting. At the plants where splitting and crumbling could be found, the total amount was comparatively small and would have no effect on the operation of the filters. Although more pieces of slag were affected by flaking, the total amount of such flaking did not represent any greater disintegration than by splitting and crumbling.

The durability of slag under sewage bed conditions has been tested by George. H. Gascoigne.[6] Samples of the material were placed in colanders on the surface of an operating sewage bed within range of the spray from the distributing nozzles. The

samples were left on the bed from Jan. 1927 till Feb. 1928, in which time there were 37 days during which the temperature at all times was below freezing point. The minimum atmospheric temperature was —8° F. and the maximum 99° F. Alternate wettings and dryings occurred on the bed 40-50 times daily during the period. The original size of the aggregates was 2-3 in., and the following table shows the results of the test. The fine material below $\frac{3}{16}$ in. (lost through the holes in the colander) was not calculated:

AGGREGATE	PIECES TESTED		CONDITION AFTER TEST		
	No.	Weight, Gm.	Pieces over 1″	Fines $\frac{3}{16}$″ -1″ Weight, Gm.	Per Cent by Wt.
Slag—1	20	3117	20	0	0
Slag—2	20	2939	20	22	.7
Slag—3	20	1938	20	10	.5
Slag—4	20	3969	20	5	.1
Slag—5	20	3336	20	18	.5
Slag—6	20	2970	20	5	.1

In view of the behavior of slag in the accelerated durability tests just outlined, it would seem superfluous to state that it is a durable and stable material, but there is one small point in this connection which may need clarification. L. G. Carmick's[10] investigations show that slag which is solid at atmospheric temperatures (in other words, as delivered on the job) will remain entirely stable and durable, but occasionally there is produced a small quantity of "limy" slag which crumbles to powder during cooling if it is not processed correctly. It has been found that slow cooling will cause the calcium orthosilicate in certain slags to pass through three forms (alpha, beta and gamma), the last of which involves a volume increase of about 10 per cent and disintegration of the slag. However, if the general practice is followed and the molten slag is poured in thin layers so as to chill quickly and solidify it, the calcium orthosilicate is arrested at the beta form, which is entirely stable and involves no volume change. Tests have proved that any disintegration which takes place does so before the slag has cooled, hence no slag likely to crumble will be found in the finished commercial product. The small amount of fine material developed in the pits by crumbling is removed by the screening opera-

tions, and furthermore has reached its final form and is entirely inert as proved by tests. C. C. Hommon[5] reports a case where hot slag which was visibly crumbling was immersed in water and the crumbling was completely arrested. Further, the cooled slag withstood 5 cycles of sodium sulphate successfully. He also cites the instance of a large piece of slag, part of which had crumbled during cooling; the solid material remaining after cooling withstood 20 cycles of sodium sulphate. The final proof of the relative unimportance of crumbling slag is the fact that there has never been any crumbled or disintegrated slag found in slag concrete.

Like slag aggregate, slag concrete receives its most severe durability test in connection with sewage disposal beds. Concrete is used for the walls and floors of the beds, and also for primary and secondary settling tanks. All these receive the weathering that any exposed concrete is subject to, and in addition the wetting and drying, freezing and thawing caused by the conditions under which such plants are operated. The character of the sewage itself probably has a decided effect in bringing about disintegration, but slag concrete has been used with entire satisfaction for such construction in 19 sewage beds in the United States, including the temperature ranges to be found in New York, Pennsylvania, Ohio, Alabama and Tennessee.

A report of the A. S. T. M. Committee on Concrete Aggregates[11] makes the following conclusive statement with regard to the durability of slag concrete:

> A large amount of test data has shown this material to be acceptable as concrete aggregate, and there is also a large amount of data from the field in testimony of the permanence and durability of slag concrete structures.
>
> No restriction has been placed upon the sulphuric content of slag, for the reason that inspections made by members of the Committee of reinforced slag concrete structures in the course of demolition showed no corrosion of reinforcement that could be attributed to the slag, nor is there any published evidence that such corrosion has been observed so far as the Committee is aware.

The last sentence of the foregoing statement by Committee C-9 answers a question which has often been raised by engineers: "Does slag concrete have any corrosive effect on steel reinforcement?" There has never been a case where slag has been shown

to have affected the reinforcing steel in any way, and many concrete authorities have expressed a decided belief that such action cannot happen. If the concrete is dense and the steel placed at a proper depth from the surface, every possible protection has been afforded, and the steel will be unaffected.

If slag has any corrosive effect on steel, it would have come to light in connection with other uses of the material than reinforced concrete, where the steel is protected from air and moisture. For example, in sewage disposal beds the feeder and riser pipes are covered with slag to a depth of 5-8 ft., and liquid sewage is applied continuously, giving rise to the very conditions which should produce decided deterioration—air, moisture, and even acids. The liquid running down over the slag and thence over the piping undoubtedly produces a more severe condition tending to affect the iron than exists in reinforced concrete, and yet there is a total of 37 slag sewage disposal beds in the United States with service histories up to 21 years, in none of which are there any recorded data that the pipes deteriorated more quickly than usual. This is in spite of the fact that in several cases stone and slag beds have formed units of the same plant, with the opportunity to compare the behavior of each.

The Masonry Committee of the Amer. Railway Engineering Association[12] has also recorded its inability to find instances of corrosion of steel in slag concrete:

> The extensive use of slag concrete over a period of years has demonstrated its permanence for buildings, retaining walls, bridges and foundation work where the structure is exposed to ordinary conditions. No case has been brought to notice where embedded steel became corroded in slag concrete.

The U. S. Bureau of Standards[1] has conducted tests to determine whether there is any corrosive effect of slag, and made the following report:

> To the extent of the tests there was no sign of disintegration due to sulphide sulphur or other causes. In the past there has been some hesitation on the part of engineers to permit the use of slag aggregate without certain special limitations on the material such as weight per cu. ft. and sulphur content. Experience has shown, however, that there is probably no greater need for such restrictions in the case of blast furnace slag than for other commonly used and accepted aggregates.

Sanford E. Thompson[14] made an investigation of slag concrete structures in a number of cities in order to determine the durability of the material, and reported:

I have made chemical and physical tests and also visited several cities where slag concrete has been used for a number of years. As a result of careful examination of various structures made with slag concrete, and interviews with users of slag concrete, I find no evidence of disintegration where portland cement was used. In certain cases with puzzolan cement, the concrete is not in first-class condition, but this is to be expected with any puzzolan cement concrete laid in air. No authentic cases of deterioration of slag concrete made with portland cement, or of rusting of steel embedded in such concrete, have been discovered.

Tests at the Pittsburgh Testing Laboratory[15] showed no corrosion of steel in 5-year old concrete made with slag aggregate from 9 sources in the United States. Slight rust spots were found where air pockets had formed, but these were common to all the aggregates used in the tests—limestone, dolomite, trap-rock, granite, gravel and blast furnace slag.

A. T. Goldbeck[19] is one of the many concrete authorities who have been unable to find a case of slag concrete corroding steel reinforcing, and states:

I know of no cases of well-defined corrosive action of reinforcing steel in slag concrete. I examined, some 8 years ago sections of reinforcing steel removed from a concrete slab in our presence at the Swedeland (slag) plant in Pennsylvania. The sections removed were about three feet long. Two of them were perfectly sound, one end of the third rod had a few pits, showing no rust, but the surfaces were perfectly bright. Since the slab removed had been situated between electric railroad tracks and since there was considerable moisture present, I have always felt that this pitting might have been due to electrolytic action. We were told that this slab had been constructed 11 years previous to the time of our inspection.

Other statements regarding the durability of slag concrete have been made by Wilbur J. Watson, consulting engineer, Cleveland, Ohio[17]; A. D. Bender of Cleveland Macadam Co.[18]; John M. Goehring of Duquesne Slag Products[18]; L. W. Walter of the Erie Railroad[20]; F. Tschudy of the Tennessee Coal, Iron & R. R. Co.[18,21]; C. S. Hill of Eng.-News Record[22]; and W. S. Harger, of the New York State Highway Dept.[23].

Resistance to High Temperatures and Fire

When portland cement concrete is subjected to high temperatures such as commonly occur in building fires, the type of aggre-

gate used may have a decided influence on the resistance of the concrete to deterioration. Blast furnace slag experiences no disruptive change of volume under such conditions because of its low and uniform thermal expansion at all temperatures.

One of the earliest fire tests on record was that conducted by the British Fire Prevention Committee[24] in 1906, consisting of a fire endurance test followed by a hose stream test, on a loaded floor. The slag concrete bay in the floor was reported as showing slightly less buckling and much less cracking than other bays containing gravel, granite, clinker and brick as aggregates. Only the bay containing coke breeze as aggregate was in better condition.

Later tests by the British Fire Prevention Committee[25] in 1917-19 included as aggregates, two blast furnace slags, six gravels, seven sandstones, four limestones, eleven granites, five bricks, two coke breezes, two pan breezes and three coal clinkers, in both plain and reinforced concrete slabs. Fire and hose stream tests were made on the loaded slabs, and thermal conductivity values determined. The report of the tests states:

> Coarse aggregates of clean broken bricks and burnt clays gave the most satisfactory results from strength and resistance to fire. Blast furnace slag appeared to be almost as good. Pan breeze and clinker were fairly satisfactory. The gravels, sandstones, granites and other highly siliceous aggregates were unsatisfactory, while the fine-grained igneous rocks, such as basalt, gave satisfactory results. The limestones were better than the siliceous aggregates. In parallel with the tests of plain and reinforced concrete slabs, the heat conductivity of the various concretes was measured. The coarse aggregates in the slabs which did not attain to 1200° F. were slag, limestone, basalt, andesite, coke breeze, broken brick and whinstone. The highest temperatures at points near the top of the slabs were attained with concretes having as coarse aggregates siliceous gravels, calcareous gravel, coke breeze and quartzite.

W. A. Hull[26] reports fire tests on loaded concrete columns which were later tested in compression. Part of his conclusions follows:

> The results contribute additional evidence that gravels of 3 distinct types, all high in quartz, give less satisfactory results under fire conditions than concretes from limestone, traprock and blast furnace slag aggregates. Columns of these types from traprock and blast furnace slag concrete show no tendency to spall or crack to any important extent under the conditions of the standard 4-hour fire test. In all cases, columns from traprock and slag aggregates have

shown themselves capable of bearing considerably more than twice their respective working loads before cooling, following the 4-hour fire test. The observation that neither the traprock nor the slag concrete appears to have any tendency to spall or any other malignant tendency under the conditions of these tests is important and reassuring.

Fire tests of concrete building units at the Underwriters' Laboratories[27] in Chicago resulted in the conclusion that "Coarse aggregates of limestone, calcareous pebbles, cinders or crushed slag perform with comparative similarity under standard fire exposure conditions."

Tests of German concrete aggregates by Dr. Kurt Endell[28] included blast furnace slag, granite, basalt, limestone, quartz, quartzose and burnt brick, and resulted in the following report:

Quartz and granite expand up to 930° F. and then undergo an alteration which is accompanied by cracking of the material. Basalt and blast furnace slag show a smaller expansion due to heat and one which proceeds uniformly. The practical results of the investigation show that for heat-resisting structures quartz-containing mixtures should not be used, but aggregates composed of blast furnace slag, basalt and limestone should be employed because of their slow and uniform expansion.

In October, 1925, at Birmingham, Ala., a small house built of slag concrete tile was filled with inflammable materials and ignited. While the walls were white hot a hose stream was turned on it, but the State Fire Marshall, Chester E. Johnson[29] reports:

On inspection of the building no cracks of any nature were found, nor was any disintegration or crumbling of the tile apparent. On breaking through the wall and examining the interior webs of the tile, no cracks or other evidence of failure were found. The ceiling was undamaged, and the concrete tile roof showed no evidence of having been affected. The units plainly demonstrated their fire-resisting qualities and are to be highly recommended for use in the construction of permanent and fireproof structures.

Exactly 1 year later the same type of tile underwent a severe test of its fire-resisting properties in actual construction. During the building of the Calvary Baptist Church in Tuscaloosa, Ala., using slag concrete tile, the structure was destroyed by fire except for the tile, which withstood the flames in an extraordinary manner. Quoting from the report in *Concrete*:[30]

Fortunately for the underwriters and the congregation, the concrete tile walls resisted the flames in a remarkable manner. The blaze gained rapidly, probably having made considerable headway before discovery. Then

for two and a half hours the structure burned fiercely, consuming timbered and wooden interior, scaffolding, floors and finally the roof, which was supported by unprotected steel trusses. The walls were relatively quite high for their length, but this fact has no bearing except to accentuate their good behavior in the fire. There were five large arched windows in each side, as well as other large openings which provided plenty of draft and tended to weaken the walls. When the fire was finally subdued . . . two of the main walls had been carried down. These walls were forced over by the collapse of the roof trusses after having been deprived of the bracing effect of the previously collapsed floor members. The high front wall, one of the sidewalls, and the chimney remained standing. The chimney will doubtless be used in rebuilding the structure. The stucco apparently is in perfect condition except where blackened by smoke, although subject to the very severe test of having water from the fire hose thrown upon it while in an extremely hot condition. There was no discernible distortion of these walls at any point, a rather remarkable fact under the circumstances. No cracking or spalling of the units was found and the walls which were overturned broke up into a few large pieces of masonry apparently as strong as any first-class masonry not exposed to fire. As a result of the fire performance of the concrete tile in this fire, the same material was purchased for the rebuilding of the structure.

George H. Sanger[31] cites the use of slag concrete at the plant of the Northwestern Iron Co. at Mayville, Wis., as an example of its resistance to high temperatures:

In the last five years we have placed nearly 30,000 yards of slag concrete for various purposes and subject to a wide range of conditions and I have never known of a failure that could in any way be traced to the slag. In places where the concrete has been subjected to a considerable amount of heat, some few cracks have developed, but they were undoubtedly due to the expansion.

Our cooling pit at the pig machine probably represents the most severe conditions imposed upon any of our concrete. The pit is first filled with cold water, into which the pig machine discharges red-hot pig iron, which soon heats the water to boiling point; at the end of the cast the hot water is drawn off and the pit is refilled with cold water. As this cycle occurs every two hours the concrete is in a continual state of expansion and contraction, and is also in direct contact with the boiling water and steam. Thus far there have been no signs of spalling or surface cracks; the surface is apparently in as good condition as it was when the forms were first removed.

Compressive Strength

More data have been compiled on the compressive strength of concrete than on any other quality, although recently there has been a tendency to use other specific tests along with the compressive where the concrete is to undergo a particular type of

service. For example, pavement concrete is tested for transverse strength as well as compressive. However, it is believed by most concrete authorities that the compressive strength of a concrete is a very fair general indication of all-round quality.

Other conditions of test being equal, such as cement content, water-cement-ratio, etc., there is very little difference between the compressive strengths of concretes employing the more common mineral aggregates. This is illustrated in the results of tests at the laboratory of the Portland Cement Association[32], which included as aggregates 19 slags, 27 gravels, 36 limestones, 14 granites, 11 sandstones and 14 traprocks. Since each aggregate was selected from a different source, these tests should furnish a representative picture of the relative compressive strength of slag concrete. The mix was 1 part of cement to 4 parts of dry rodded mixed aggregates, which resulted in practically equal cement content throughout. Two combinations of aggregates were used: "A" containing 38 per cent sand and "B" 48 per cent. The coarse aggregates were graded differently in each of the combinations: "A" having 25 per cent No. 4-⅜ in., 50 per cent ⅜-¾ in., and 25 per cent ¾-1½ in., while the "B" grading was 25 per cent ⅜-¾ in. and 75 per cent ¾-1½ in. The cylinders were stored 14 days in the moist room, then in air till tested at 90 days, 5 cylinders being broken for each concrete containing a different aggregate. In the "A" grading, the average of all concretes was 4393 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were as follows: Limestone—103; Sandstone—101; Granite—99; Gravel—98; Slag—97; and Traprock—96. In the "B" grading, the general average was 4217 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Limestone—102; Traprock—101; Granite—99; Slag—98; Gravel—97; and Sandstone—96. It is apparent that the difference between aggregates is not sufficient to justify precedence of one over the other.

Stanton Walker[33] has reported other tests at the P. C. A. Laboratory on 7 different mixes varying from 1:2 to 1:6, the proportioning being on the same basis as before. Limestone,

granite, gravel and slag were the aggregates tested, and two curing methods were used: (a) In damp sand for 90 days, and (b) In damp sand for 14 days and the remainder of 90 days in air. In the damp sand curing, the average value for all mixes and all aggregates was 3940 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Granite —103; Limestone—100; Slag—98; and Gravel—96. In the air curing, the general average was 3626 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Limestone—102; Granite—101; Gravel—99; and Slag—97. Here again the difference between aggregates is so slight as to be negligible.

Not quite so close an approximation of compressive strengths is noted in further tests at the P. C. A. Laboratory reported by Duff A. Abrams[34]. The aggregates were slag, limestone, gravel and granite, tested at 1 year after storage in damp sand. The proportions were 1 part cement to 4 parts of dry rodded mixed aggregates. The general average was 4312 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Gravel—115; Slag—105; Limestone—91; and Granite—87.

Tests of the U. S. Bureau of Roads recently reported by W. F. Kellerman[35] included as aggregates 3 slags, 4 limestones, 1 sandstone, 1 traprock, 1 granite, and 7 gravels, in 4 distinct gradations. Two mixes were used, 1:1.6:3 and 1:2:4, based on dry rodded volumes of aggregates. Tested at 28 days after storage in moist air, the grand average strength for the richer mix was 3682 lb. per sq. in. Taking this value as 100,the averages of the individual aggregates were: Sandstone—113; Slag—101; Granite—99; Limestone—98; Gravel—97; Traprock—92. The grand average strength for the leaner mix was 2776 lb. per sq. in. Taking this value as 100, the average of the individual aggregates were: Sandstone—113; Limestone—100; Gravel—99; Granite—99; Slag—96; Traprock—94.

Raymond Harsch's[4] investigation for the U. S. Bureau of Roads included compression tests on slag concrete specimens. These were made with slags selected from 19 different sources in the United States, the mix being proportioned 1:2:3 based on dry rodded volumes of aggregates. For check aggregates one

gravel (average quality) and one limestone (above average quality) were used. Tested after 28 days damp sand storage, the average of all concretes was 3123 lb. per sq. in., 3-5 cylinders being tested for each aggregate source. Taking this average as 100, the slag concretes averaged 104, the stone concrete 95 and the gravel concrete 85.

Nine slags from as many sources were included in P. J. Freeman's[15] ten-year concrete tests, as well as two gravels, one traprock, one granite, and two limestones. The mix was proportioned 1:2:4 based on dry compact volumes of aggregates, and compression cylinders were broken at various ages up to 10 years. The strengths of all concretes were affected similarly by the type of storage, which was 35 days in damp sand followed by the remainder of 5 years in a warm dry laboratory. At 5 years, the cylinders were stored outside in the weather until 9⅔ years, when they were placed in damp sand until tested at 10 years. Mr. Freeman states in his report:

> All concrete, regardless of type of coarse aggregate, increased in strength when stored in dry air up to the age of 1 year, and after that time decreased in strength so long as the air storage continued. The strength of the concrete was regained after storage in the weather, and at the end of 10 years it has exceeded in strength the results obtained at 1 year.

Mr. Freeman's report also states that the compressive strength was not affected by:

> (a) Weight of the slag aggregate. The compact weight varied from 64 to 84 lb. per cu. ft.
>
> (b) Chemical analyses of the slags. The silica content varied from 31.53 to 36.72 per cent; the alumina from 11.81 to 14.11 per cent; the lime from 31.75 to 45.80 per cent; and the magnesia from 1.62 to 19.43 per cent.
>
> (c) Age of the slags. Some were only a few days old when used, while others had lain in banks for as much as 15 years.

At the end of 5 years in warm dry air, the general average of all concretes was 3939 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Slag—107; Granite—102; Traprock—94; Limestone—92; and Gravel—77, these values being the average of 27 specimens of slag concrete, 6 of gravel, 3 of traprock, 3 of granite and 6 of limestone. At 10 years, the general average strength was 5616 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Granite—103; Limestone—102; Slag—100; Trap-

rock—95; and Gravel—90. The values at 10 years were the average of nine specimens of slag concrete, five of limestone, two of gravel, two of granite and one of traprock.

Transverse Strength

The earlier beam tests of concrete made in a compression machine, consisted of supporting the beam at each end and applying the load either at the center point of the top surface or at the third points. Third-point loading was used in the P. C. A. Laboratory tests reported by Duff A. Abrams[34], the aggregates being slag, limestone, gravel and granite. The proportions were 1 part cement to 4 parts dry rodded mixed aggregates, which resulted in practically equal cement content throughout. At 7 days, the general average of all concretes (7 x 10 x 36 in. beams) was 423 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Slag—106; Limestone—104; Gravel—99; and Granite—90. At 28 days, the general average was 557 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Limestone —106; Slag—104; Gravel—98; and Granite—97. The foregoing figures are based on the average of 5 breaks, except the 28 day gravel value, which is on 25 breaks.

Later tests at the P. C. A. Laboratory used the same mix, method of test, and aggregates except that sandstone was included. These were reported by H. F. Gonnerman and E. C. Shuman[36]. At 7 days, the average strength for all concretes (7 x 10 x 38 in. beams) was 454 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Limestone—112; Sandstone—101; Slag—99; Gravel—98; and Granite —90. At 28 days, the average of all concretes was 609 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Limestone—115; Slag—102; Gravel—98; Granite—95; and Sandstone—92. These values are based on an average of 5 breaks, except the 28-day gravel value, which is on 15 breaks.

Center-loading tests of slag concrete have been reported by F. H. Jackson and J. T. Pauls[37] in connection with the Arlington Circular Track experiment of the U. S. Bureau of Roads. These were on 6 x 8 x 48 in. beams tested at 90 days in a 1:1½:3 field mix. The aggregates were 9 gravels, 10 stones and 3 slags. The

average of 2 beams for each aggregate showed a general average of 575 lb. per sq. in. Taking this value as 100, the average of the slag concretes is represented by 117, the stone concrete by 99 and the gravel concrete by 95.

During the construction of a 5½-mile section of the Cleveland-Meadville Road[38] in 1928, slag concrete beams were tested daily by the cantilever test at every age from 3 to 16 days, and thereafter intermittently until 26 days. The mix was 1 part cement to 5 parts of total aggregates (fine and coarse) measured loose, and the beams were 6 x 6 x 40 in. The machine used was a portable one developed by the Ohio Highway Dept., using a worm-and-gear for applying the load and a steel extension arm. The 3-day strength was 598 lb. per sq. in. Taking this value as 100, the average strengths at other ages were as follows:

Four day—110; 5—110; 6—111; 7—117; 8—129; 9—124; 10—125; 11—116; 12—127; 13—139; 14—126; 15—122; and 16 day—130. At 26 days the strength was 817 lb. per sq. in., or an increase of 36 per cent over the 3-day strength.

The average of all slag concrete pavements built by the Ohio Highway Dept. in 1928 shows the transverse values tabulated below. These data have been furnished from the files of the department through the courtesy of A. S. Rea and D. W. Leggett[39], and represent 370 tests of 6 x 6 x 40 in. beams. The mix throughout was the same as shown for the Cleveland-Meadville Road:

AGE AT TEST DAYS	NUMBER OF BEAMS	AVERAGE TRANSVERSE STRENGTH
3	1	598
4	4	653
5	7	655
6	4	611
7	102	656
8	11	696
9	8	734
10	7	675
11	4	675
12	10	715
13	4	766
14	102	732
15	2	805

16	2	743
21	17	762
28	85	801

For concrete base work the Ohio Highway Dept. uses a leaner mix of 1 part cement to 7 parts total aggregate (fine and coarse) measured loose. The average of 107 slag concrete beams tested during 1928 showed strengths of 446 lb. per sq. in. at 7 days, 544 lb. at 14 days, 641 lb. at 21 days, and 602 lb. at 28 days.

Tests at the Ohio Highway Dept. Laboratory in 1928 reported by A. S. Rea[40] indicate that the type of testing machine, or the type of specimen, or both, affects the results appreciably. The machine used by the Ohio Highway Dept. takes a 6 x 6 x 40 in. specimen, while the original machine developed by H. F. Clemmer and Fred Burggraf[41] takes a 6 x 8 x 30 in. beam. Five slags from as many sources were tested in 2 mixes, 1:5 and 1:5½, proportioned 1 part cement to a stated number of parts of total aggregate measured in a dry loose condition (cement content respectively 6.7 and 6.4 sacks per cu. yd. for the two mixes used). The five slags were chosen to represent the extremes found in commercial practice, ranging from 61 to 89 lb. per cu ft. (dry, loose weight). The weight per cu. ft. did not seem to be reflected in the transverse strength, since the heaviest slag had only a slight advantage in strength at 7 days and this disappeared at later ages. The results of the tests are shown in the following tabulation:

MIX	AGE AT TEST, DAYS	AVERAGE STRENGTH OF SLAG CONCRETES, MODULUS OF RUPTURE	
		Ohio Machine	Illinois Machine
1:5	7	672	548
	28	761	623
	90	861	709
1:5½	7	674	556
	28	744	607
	90	818	675

Slag concrete pavements built by the Pennsylvania Highway Dept. in 1928 were proportioned by either weight or volume. The average of 1312 beam tests of slag concrete, 6470 of stone concrete, and 618 of gravel concrete are shown in the accompanying tabulation reported by H. S. Mattimore[42]. The tests

were made on a machine using a wood extension arm, the specimens being 6 x 8 x 40 in.:

MIX	AGE AT TEST, DAYS	AVERAGE STRENGTH, MODULUS OF RUPTURE Slag	Stone	Gravel
*1:2:3	10	633	583	576
	14	656	631	596
	21	681	601	—
†1:2:3¼	10	617	589	477
	14	621	612	591
	21	726	—	—
‡1:2:3½	10	634	543	476
	14	627	593	534
1:2:4	10	—	434	497
	14	596	474	528
	21	665	559	545

*By volume, witn no compensation for bulking of sand
†By volume, with compensation for bulking of sand.
‡By weight, with compensation for moisture in sand.

The U. S. Bureau of Roads tests reported by W. F. Kellermann[35] were also made with the machine having the wood extension arm, the load being applied through a worm and gear arrangement. Four limestones, 1 granite, 1 sandstone, 1 traprock, 3 slags and 7 gravels were the aggregates in two mixes,—1:1.6:3 and 1:2:4, based on dry rodded volumes of aggregates. The three slags varied in compact weight from 65 to 82 lb. per cu. ft., but this weight variation could not be traced in the transverse test results. Each coarse aggregate was tested in 4 different gradings, but the gradations as used seemed to have no effect on the transverse strength. At 28 days the average of all concretes in all gradings in the 1:1.6:3 mix showed a value of 599 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Slag—106; Limestone—100; Trap—99; Granite—98; Gravel—96; and Sandstone—93. In the 1:2:4 mix at 28 days, the general average for all gradings was 502 lb. per sq. in. Taking this value as 100, the averages of the individual aggregates were: Limestone—104; Sandstone—103; Slag—102; Gravel—97; Trap—95 and Granite—95.

Resistance to Wear

The ability of pavement concrete to resist wear is not of primary importance, since no concrete road has ever become unsatisfactory purely from attrition. Since the wear on a concrete road

surface is very small, the pavement will have failed from other causes long before the wear can become a factor in its deterioration. The best-known laboratory test for wear of concrete is the Talbot-Jones, in which the inner circumference of a steel cylinder is lined with 8 x 8 x 5 in. concrete blocks and revolved 900 times in each direction after the addition of an abrasive charge of cast iron balls weighing 200 lb. Duff A. Abrams[43] reports the results of Talbot-Jones tests on concretes containing 13 slags, 24 gravels, 26 limestones, 12 granites, 6 traprocks, 7 sandstones, 2 flints and 1 marble, proportioned 1 part cement to 4 parts of dry rodded mixed aggregates (approximately equal cement content throughout). The average depth of wear, based on 10 specimens of each aggregate sample, showed the lowest value for granite concretes,—0.34 in. The average values for the other concretes were as follows: Traprock—0.40 in.; Marble—0.42 in.; Limestone—0.44 in.; Sandstone—0.45 in.; Flint—0.46 in.; Slag—0.48 in.; and Gravel—0.51 in. In later tests[44] designed to show the effect of cement content upon wearing resistance 8 mixes were used varying from 1:1 to 1:6, proportioned as above. Granite concrete showed the least average wear for all mixes,—0.44 in., followed by slag with 0.49 in., limestone with 0.51 in., and gravel with 0.54 in.

In the Circular Track Experiment of the U. S. Bureau of Roads[37] the Talbot-Jones test was used as a laboratory check on the wearing resistance of concrete which later was subjected to the actual service test of chain-tire traffic. The three slag concretes showed an average depth of wear in the Talbot-Jones machine of 0.25 in., the 10 limestone concretes 0.28 in., and the nine gravel concretes 0.30 in. The actual track test consisted of running two solid-rubber-tired truck wheels over sections of the various concretes. The wheels were loaded to 6,000 lb. and run over the track 55,000 times, but the wear from this operation was negligible so the wheels were equipped with tire chains and an additional 25,000 runs made. The average depth of wear for the nine gravel concretes was 0.31 in., for the three slag concretes 0.37 in., and for the 10 stone concretes 0.46 in. The best slag, with a wear of 0.27 in., made about the same showing as the best stone and gravel concretes. That this test was more severe than actual

traffic conditions is noted in the conclusions of the report, where it is stated:

> It is realized that chain traffic on concrete highways is not dense enough except in isolated instances to cause any such wear of the surface of a pavement as was produced on the test sections. Wear, however, does take place at the unprotected edges of joints and cracks. It was believed that the relative resistance offered by the various sections to the chain traffic would be a fairly reliable index of the ability of the materials to resist the combined destructive influences of traffic, whether such influences produce wear at the joints or cracks or cause surface disintegration.

Toughness

Toughness in concrete is essential for whatever purpose it is to be used; buildings must withstand vibration and shocks, and pavements must be able to stand up under the impact of traffic. H. S. Mattimore[45] reports the results of impact tests on concretes containing slag, traprock, limestone, sandstone, slate and gravel, in 3 volumetric mixes,—1:1½:3, 1:2:3 and 1:2:4. The test machine consisted of a striking head, mounted on a frame, which was raised and released by a cam. The striking points were horse shoe calks with springs fitted to them to give ½ in. play so as to allow for wear of the matrix between the aggregate. The specimen was rotated by a dog attachment so that successive blows would be delivered to different parts of the surface. The effective blow was 29 lb. dropping 4 in. at the rate of 90 per minute.

The molded cylinders used in the test were made from the concrete going into the Lancaster Test Road built by the Pennsylvania Highway Dept. in 1919-20. Cores were also drilled from the pavement after 8-15 months. When tested under 5000 blows of the machine, the average loss in weight of the various specimens was as represented by the values in the following tabulation, which are expressed as "impact coefficients," a high coefficient indicating a high loss, and vice versa:

AGGREGATE	NUMBER OF CORES	1:1½:3 MIX		1:2:3 MIX		1:2:4 MIX	
		Drilled	Molded	Drilled	Molded	Drilled	Molded
Sandstone	35	115	114	115	140	90	82
Limestone	46	116	138	97	140	91	104
Slag	22	142	211	146	148	149	153
Gravel	14	191	161	168	152	212	165
Slate	16	191	193	145	134	156	137
Traprock	6	—	—	—	200	—	150

A summary of the foregoing tabulation for all mixes and both conditions of test shows an average coefficient of 133 for all concretes. Taking this value as 100, the averages of the individual aggregates were: Sandstone—83; Limestone—84; Slate —115; Slag—117; and Gravel—130, indicating an intermediate toughness for slag concrete. However, Prof. Curtis C. Myers'[2] tests at University of Cincinnati showed slag concrete tougher than either limestone or gravel concrete in a 1:2:4 mix. Five-inch cubes of concrete were first tested in the impact machine, which consisted of a swinging weight striking a blow equal to a 25-lb. weight falling 15 in., the load being concentrated on a 1-in. diameter striking point. The gravel concrete withstood 6 blows, the stone concrete 7 blows, and the slag concrete 10 blows before failure. Concrete beams were then tested in the machine using slag and stone as aggregates, and increasing the height of the blow each time. The stone concrete absorbed 8 blows before failure against 12 for the slag concrete, each of the last 4 on the slag concrete being more severe than that which caused failure of the stone concrete.

George W. Hutchinson[46] reports impact tests on limestone, slag and gravel concretes of equal cement content (6¾ sacks per cu. yd.) in which the testing machine consisted of a 10-lb. weight falling perpendicularly on the specimen from a constant height. The specimen was a 20-in. concrete disk 6 in. in diameter, supported on 3-point rubber-padded bearings, and the shock was transmitted through a 3-in. steel ball resting on the center of the top surface. The average of several hundred tests showed that limestone concrete had withstood 138 blows before failure, slag concrete 100 blows and gravel concrete 62 blows, but the author points out that there was equally as much variation within one type of aggregate as there was between different types.

Workability and Yield

Workability is defined as that quality in concrete which provides ease in mixing and handling, and allows the mixture to be readily placed without tangible voids, honeycombing or segregation.

Slag in common with other crushed aggregates, tends to give harsher mixtures than rounded aggregates because of its rougher

surface and higher voids, but this tendency can be largely overcome by attention to proper grading, and the use of a somewhat higher ratio of fine to coarse aggregate than would be required for rounded aggregates. This so-called "over-sanding" has been proven beneficial in every way, according to tests at the U. S. Bureau of Standards[47] with slag, limestone and gravel aggregates. The conclusions state:

> The tests showed (1) That for the various combinations of fine and coarse aggregates the amount of sand required to give a strength at least as great as that indicated by the normal water-cement-ratio strength-relation varied from about 33 to about 50 per cent of the total aggregate, (2) That the percentage of sand as determined gave a satisfactory workable mix, (3) That it was about the smallest percentage of sand which would give a workable mix, and (4) That these same percentages of sand gave higher strengths per barrel of cement per cu. yd. of concrete than did any other combinations of the same aggregates; that is, they gave approximately the maximum economy of cement.

The above conclusions are of great importance to the user of crushed aggregates, since they indicate that "oversanding" not only gives a workable mix but actually shows maximum economy in cement. This point can not be too highly stressed, because in the past arbitrary proportions of 1:1½:3, 1:2:4 etc. have been used with crushed aggregates in many cases where slightly more sand and less coarse aggregate would have greatly increased the workability, at the same time slightly increasing the strength and yield. This is brought out very forcibly in earlier experiments at the Bureau of Standards[48] reported in 1920. A limestone concrete in a 1:2:4 mixture was found to be harsh and segregating, while a 1:3:3 mix of the same materials not only gave satisfactory workability but higher 28-day strength, in spite of the fact that less cement was used per cu. yd. of concrete. Further tests showed that all mixes with the same proportion of cement to total aggregates had substantially the same strength, and that the oversanded mixes consistently used less cement.

Yield is the volume of concrete resulting from given quantities of cement and aggregates, and may be expressed in the following different ways:

1. The ratio of the volume of finished concrete to the volume of mixed aggregates, dry and rodded. Thus if a mix of 1 sack of cement and 4 cu. ft. of rodded mixed aggregates results in 4.4 cu. ft. of concrete, the yield is 1.10, or 110 per cent.

2. The ratio of the volume of finished concrete to the volume of the coarse aggregate, the latter being measured in any definite way. Thus if a mix of 1 sack of cement, 2 cu. ft. of sand, damp and loose, and 3 cu. ft. of coarse aggregate, damp and loose, results in 3.9 cu. ft. of concrete, the yield under these conditions is 1.30 or 130 per cent of the volume of the coarse aggregate as measured.

3. The volume of concrete of any proportions produced by one sack of cement. This is more often expressed as the reciprocal measure, viz: the number of sacks of cement contained in a cubic yard of concrete, and this number divided by 4 (to convert to barrels) is commonly referred to as the "cement factor." Thus if 6.4 sacks of cement are required for a cubic yard of concrete, the cement-factor is 1.6.

This last-mentioned method of expressing yield is now the one most commonly used, and it has the advantage of indicating the type or quality of concrete more definitely than the time-honored designation: 1:—:—, or parts of cement to parts of fine aggregate to parts of coarse aggregate. This fact is worth remembering in that recent discussions of the merits of different types of coarse aggregate have emphasized the necessity of comparing concrete mixtures on the basis of equal cement content, and when this is done with heed to the proper balance between fine and coarse aggregate for workability, the differences in concrete making properties of the different coarse aggregates become insignificant. Unfortunately this basis of equal cement content in comparative tests has not been generally used up to this time and most of the test data quoted in this report are of necessity taken from tests based on like proportions of cement and aggregates by volume or by weight.

Weight proportioning was used by Fred Hubbard[50] in comparative yield tests which he has reported using slag, limestones, traprock, gneiss and gravel as aggregates. The materials were proportioned on the basis of their respective dry weights, corresponding to a volumetric proportion of approximately 1:2:3 field mix. The gravel concrete showed the lowest cement factor, —6.80 sacks per cu. yd. of concrete, followed in order by gneiss with 6.91, traprock with 7.16, limestone No. 1 with 7.28, slag with 7.32 and limestone No. 2 with 7.32. In a leaner proportion

corresponding to approximately 1:2½:3½ field mix, limestone No. 2 and slag again had the same cement factor,—6.31 sacks per cu. yd. of concrete.

Slag as Fine Aggregate

Many more or less successful attempts have been made to introduce the finer sizes of slag (both air-cooled and granulated) as a substitute for natural sand in concrete, and a number of strong and durable structures have been and are being built in this way. Two prejudices had to be overcome before slag could be used as fine aggregate: First, the natural reluctance to change from a known to a practically unknown material; and Second, the fact that the resulting mix is somewhat lacking in workability. Laboratory and service tests have removed all doubt as to the strength and durability of concrete made with slag fine aggregate, while the workability of such a mix can be greatly improved by the addition of a portion of fine sand or a small amount of powdered slag, diatomaceous earth, hydrated lime, etc.

The control tests for the Circular Track investigation of the U. S. Bureau of Roads[37] showed satisfactory results for an all-slag concrete in compressive strength, transverse strength and resistance to wear. The transverse tests were made in the compression machine with center-loading, and the wear tests in the Talbot-Jones machine. Nine gravel concretes, 10 stone concretes and 4 slag concretes made with natural sand were included in these tests, as well as 1 all-slag concrete made with air-cooled slag screenings as fine aggregate. Taking the average of all concretes as 100 in each case, the relative values of the individual concretes in a 1:1½:3 field mix at 90 days were as shown in the accompanying table. With one exception, the all-slag concrete showed higher strengths and less wear than the concretes made with natural sand as fine aggregate:

KIND OF CONCRETE	COMPRESSION STRENGTH	TRANSVERSE STRENGTH	WEAR TEST
All-slag	104	133	68
Average of 3 slag concretes	101	112	88
Average of 10 stone concretes	105	97	97
Average of 9 gravel concretes	93	93	104

With reference to the foregoing table it should be stated here that the relation indicated by the laboratory wear tests was not borne out in the actual test on the track. The all-slag concrete showed more wear under tire-chain traffic than all the other concretes with the exception of one slag concrete and two stone concretes, which led F. H. Jackson and J. T. Pauls to state in their conclusions from the tests that "Slag or stone screenings are, in general, unsatisfactory as substitutes for natural sand as fine aggregates in concrete road construction."

Other tests on slag as fine aggregate have been reported by Curtis C. Myers[2] who found that an all-slag concrete withstood impact better than other concretes made with natural sand: and by Duff A. Abrams[52] who found that gravel concrete made with granite, slag, limestone and traprock screenings as fine aggregates were somewhat weaker (in compressive strength) than sand-gravel concrete.

The use of slag as fine aggregate has been largely confined to concrete construction around the steel plants. Fifty all-slag concrete houses were built at Youngstown, Ohio, in 1919 by the Carnegie Steel Co., and similar construction was used in recent additions to slag plants at Youngstown, East Toledo and Massillon, O. The Ford Hotel at Buffalo, N. Y., was built with an all slag concrete in 1923, and in 1916 four slag concrete bridges were built at Pottsville and St. Clair, Pa., using as fine aggregate equal parts of natural sand and slag sand.

BIBLIOGRAPHY

1. Fred Hubbard: "Standard Slag Co. Laboratory Report on Abrasion Tests of Republic Slag," May 1928.

2. Myers: "Slag as Aggregate for Concrete Ships," Page 152, *Iron Age*, July 18, 1918.

3. "Slag as Concrete Aggregate," page 107, Proc., A. C. I., 1917.

4. Harsch: "Blast Furnace Slag as Concrete Aggregate," Proc., A. S. T. M., 1923.

5. Hommon: "Report on Crushed Blast Furnace Slag as Medium in Sewage Trickling Filters," 1929.

6. Gascoigne: "Investigation of Limestone and Slag for use as Filtering Media in Sewage Trickling Filters," 1929.

7. Hubbard: "Tests of Blast Furnace Slag as Produced by Standard Slag Co.," 1929.

8. Orton: "Report to Standard Slag Co.," Aug. 13, 1914.

9. Bureau of Standards: "Durability of Concrete Aggregates," Technical Bulletin No. 123, 1927.

10. Carmick: "Study of Composition of Blast Furnace Slags," Proc., A. S. T. M., 1921.

11. Comm. C-9: "Report of Comm. C-9," Proc., A. S. T. M., 1923.

12. A. R. E. A.: "Report of Masonry Committee, Appendix D," p. 738, Bulletin of A. R. E. A., Feb., 1918.

13. Bureau of Standards: "Blast Furnace Slag as Concrete Aggregate," Report, Sept., 1921.

14. Thompson: "Slag as Concrete Aggregate," Proc., A. C. I., 1917.

15. P. J. Freeman: "Long Time Tests of Concrete Using Various Aggregates," p. 879, *Engineering News Record*, Dec. 1, 1927.

16. *Concrete:* "In Wrecked Slag Concrete Little Corrosion of Reinforcing Shown," p. 128, Mar., 1921.

17. Watson: "Steel Still Bright in Old Slag Concrete," p. 358, *Engineering News Record*, Feb., 1924.

18. Bender and Goehring: "Utilization of Iron and Steel Works' Slags," Proc., Engineers' Soc. of Western Pennsylvania, 1915.

19. Goldbeck: Correspondence with Nat. Slag Assn., July 15, 1922.

20. Walter: "Blast Furnace Slag as Aggregate," by W. A. Aiken, Proc., A. S. T. M., 1914.

21. Tschudy: "Use of Blast Furnace Slag as Aggregate," p. 210, *Concrete-Cement Age*, Apr., 1915.

22. Hill: "Slag Concrete Roads," p. 439, *Engineering News Record*, Sept. 14, 1922.

23. Harger: "Rural Highways and Pavements," published by McGraw-Hill Book Co., N. Y. City, 1924.

24. British Fire Prev. Committee: *Engineering News*, Feb. 1, 1906.

25. British Fire Prev. Committee: Proc., A. C. I., p. 287, 1925.

26. Hull: "Fire Tests of Concrete Columns," Proc., A. C. I., p. 89, 1919.

27. Underwriters' Lab.: "Retardant Report No. 1555," May, 1924.

28. Endell: "Effect of High Temperatures," p. 62, *Rock Products*, Oct., 16, 1926.

29. Johnson: *Concrete*, p. 16, Oct., 1926.

30. *Concrete:* "Concrete Tile Proves Merit," p. 13, Oct., 1926.

31. Sanger: "Slag," booklet of Cleveland Furnace Co., 1907.

32. P. C. A.: "Series 135, P. C. A., Laboratory."

33. Walker: "Modulus of Elasticity of Concrete," Proc., A. S. T. M., 1919.

34. Abrams: "Flexural Strength of Plain Concrete," Proc., A. S. T. M., 1922.

35. Kellermann: "Effect of Type and Gradation of Coarse Aggregate," p. 72, *Public Roads*, June, 1929.

36. Gonnerman and Shuman: "Compression, Flexure and Tension Tests of Plain Concrete," Proc., A. S. T. M., 1928.

37. Jackson and Pauls: "Accelerated Wear Tests of Concrete Pavements," Proc., A. S. T. M., 1924.

38. "Report of Concrete Beams on Intercounty Highway 15, Sections H and I", Ohio Highway Dept., July, 1928.

39. Rea and Leggett: "Report on Concrete Beams, Ohio Highway Dept., 1928."

40. Rea: "Report of Tests on Slag and Slag Concrete," Ohio Highway Laboratory Report, July, 1928.

41. Clemmer and Burggraf: "Transverse Testing of Concrete," Proc., A. C. I., 1926.

42. Mattimore: "Cantilever Beam Tests, Pennsylvania Highway Dept.," 1928.

43. Abrams: "Wear Tests of Concrete," Proc., A. S. T. M., 1921.

44. "Series 98, Portland Cement Association Laboratory."

45. Mattimore: "Service Test Road, Route 129, Lancaster County, Pa.," Pennsylvania Highway Dept., Report, 1921.

46. Hutchinson: "Proportioning Concrete Materials," Proc., A. C. I., 1925.

47. Bureau of Standards: "Effect of Coarse Aggregate on Compressive Strength of Concrete," Technical News Bulletin, June, 1928.

48. Bureau of Standards: "Tests of Oversanded Mixtures," p. 79, *Concrete*, May, 1920.

49. Levison: "Inundation Method of Measuring Sand," National Sand and Gravel Bulletin, Aug., 1928.

50. Hubbard: "Relative Yield of Various Coarse Aggregates," Standard Slag Co. Laboratory Report, Jan. 13, 1928.

51. "Slag for Building," booklet by Standard Slag Co., 1915.

52. Abrams: "Stone Screenings as Fine Aggregate," p. 128, *Concrete*, April, 1923.

53. Santee: "Fifty Double-Wall Houses for Carnegie Employees," *Concrete*, Jan., 1919.

54. "Ornamental Bridge at Akron of Slag Concrete," p. 769, *Engineering News*, Oct. 21, 1915.

55. "Completion of Notable Concrete Viaduct," *Scientific American*, Feb., 1923.

56. "Girard's Million-Dollar Bridge," p. 17, *Highway Topics*, Oct., 1928.

57. Leggett: "Marking Dedication of New Ashtabula Viaduct," Ashtabula (O.) *Star-Beacon*, Oct. 29, 1928.

58. Fry: "Long Arch Bridge Built of Slag Concrete," p. 840, *Engineering News Record*, May 19, 1921.

59. Wilcox: Correspondence with Birmingham Slag Co., Jan. 23, 1922.

60. Boynton: Correspondence with Birmingham Slag Co., Feb. 1, 1922.

Readers are referred to the JOURNAL *for February, 1931, for discussion which may develop. Such discussion should reach the Secretary by January 1, 1931.*

Discussion of Progress Report of Committee 105

"Reinforced Concrete Column Investigation"*

BY HERBERT J. GILKEY†

A RECENT paper by Richart and Jensen[1] reports that Haydite concrete having an ultimate strength and bond resistance about equal to those of concretes from ordinary aggregates, has a modulus of elasticity that is decidedly lower. This fact means that the values of "n" are increased and that a correspondingly higher stress can be transferred to the steel for a given stress in the concrete.

From this very interesting fact it appears that Haydite concrete may have unique possibilities in the realm of columns and other reinforced compressive members. This point has been enlarged upon in a discussion of the Richart and Jensen paper[1].

It is probably too late to inject any phase of Haydite concrete into the present project even if it were deemed desirable to do so. It does appear that this aspect of the material has enough novelty and promise in it to warrant some sort of a separate experimental reconnaissance over the field.

---

*JOURNAL A. C. I., April, 1930; *Proc. A. C. I.*, Vol. 26, p. 601.

†Professor of civil engineering, University of Colorado, Boulder, Colo.

[1]Proc. A. S. T. M., 1930, Part II.

Discussion of Paper by P. M. Woodworth

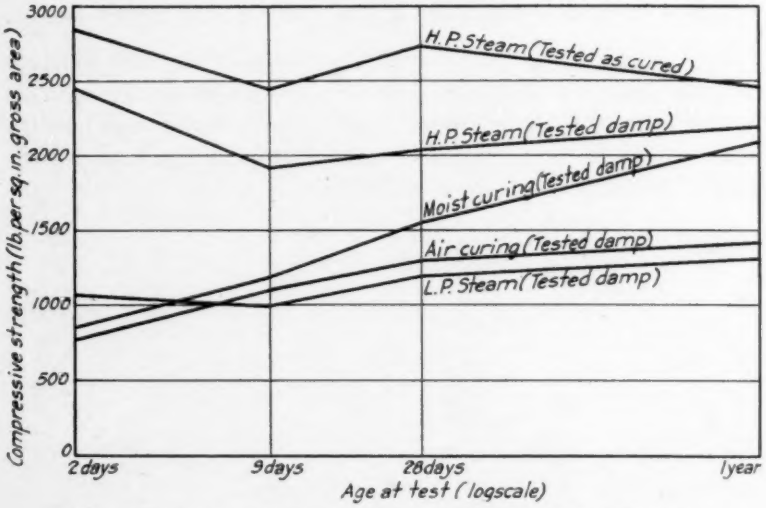
"Some Tests of Concrete Masonry Cured With High-Pressure Steam"*

AUTHOR'S CLOSURE

This investigation has been completed with the testing of the one-year specimens. A summary of the results is contained in the accompanying table A and typical age-strength relations are plotted in the figure.

The outstanding feature of these tests is that concrete units cured with steam under 100-lb. pressure for 12 hr. and then in air at 50 per cent relative humidity, developed strengths which averaged about 15 per cent more at 2 days and about 5 per cent

*A. C. I. Journal, Feb. 1930, *Proceedings*, Vol. 26, p. 504.



Effect of curing on compressive strength of concrete masonry units

SOME TESTS OF CONCRETE MASONRY UNITS CURED WITH HIGH PRESSURE STEAM

TABLE A—*Compressive Strength of Vibrated Concrete Masonry Units*

Compressive tests of 5 by 3¾ by 12-in. concrete tile.

Cement from fresh warehouse stock.

Aggregate: Crume Brick Co. bank sand and crushed gravel graded 0-⅜-in.

Water: 8½ gal. per sack corrected for absorption of aggregate.

Mix: 1:4:6 damp, loose volume; 1:9.6 dry weight.

Concrete vibrated in molds for 50 seconds at 3600 r. p. m.

Specimens removed from molds 36 to 48 hr. after molding and air-cured until test.

Specimens capped with gypsum 6 hr. before testing.

Unless otherwise noted each value is the average of three tests made on the same day.

Values in parentheses are percentages of 28-day strengths of moist-cured tile.

Age Before Curing Hr.	Method of Curing	Condition When Tested	Compressive Strength lb. per sq. in. Gross Area			
			2-Da.*	9-Da.	28-Da.	1-Yr.
½	12½ hr. in saturated steam at 100 lb. gage pressure then air-cured at 70° F.	Damp	2250 (144)	1820 (117)	1890 (121)	2150 (137)
		As Cured	2900 (186)	2500 (160)	2550 (164)	2490 (160)
4	"	Damp	2440 (157)	2020 (131)	2060 (132)	2250 (144)
		As Cured	2960 (190)	2560 (164)	2620 (166)	2620 (168)
8	"	Damp	2530 (161)	1970 (126)	2150 (133)	2420 (155)
		As Cured	2760 (177)	2580 (165)	2990 (192)	2300 (147)
24	"	Damp	2560 (164)	1880 (121)	1990 (128)	1940 (124)
		As Cured	2840 (182)	2140 (137)	2740 (176)	2460 (158)
Average	"	Damp	2450 (157)	1920 (123)	2020 (130)	2190 (140)
		As Cured	2760 (187)	2450 (157)	2720 (174)	2470 (157)
4	12½ hr. in steam at 125° F. and atmospheric pressure then air-cured at 70° F.	Damp	1070 (69)	1000 (64)	1190 (76)	1320 (85)
		As Cured	1150 (74)	1270 (81)	1810 (116)	1430 (92)
6	12½ hr. under damp straw at plant temperature then air-cured at 70° F.	Damp	770 (49)	1110 (71)	1310 (84)	1420 (91)
		As Cured	1060 (68)	1360 (87)	1930 (124)	1570 (101)
0	48 hr. under damp straw at plant temperature then moist - cured at 70° F.	Damp	860 (55)	1190 (76)	1560 (100)	2090 (134)
		Oven Dry				2950 (189)

*2-Day Tests made on 200,000 lb. Testing Machine at Bowser-Morner Testing Laboratories, Dayton, Ohio.

Tests at later ages made on 300,000-lb. Testing Machine at Portland Cement Association, Chicago.

more at 1 year than that of similar units moist-cured for a period of one year. These comparisons are based on units tested in a damp condition.

It appears that high-pressure steam-curing furnishes a means of developing relatively high concrete strengths at very early ages. The promising results obtained by this method of curing show the desirability of further study by manufacturers of concrete masonry units and other concrete products in order that its possibilities may be developed to the greatest extent.

ABSTRACTS

ABSTRACTS

of the current literature of cement and concrete

PREPARED UNDER THE DIRECTION OF THE
AMERICAN CONCRETE INSTITUTE
COMMITTEE ON ABSTRACTS

J. C. WITT, Chairman, (*Materials*)
H. F. GONNERMAN (*Properties of Concrete*)
F. E. RICHART (*Engineering Design*)
REXFORD NEWCOMB (*Architectural Design*)
THEODORE CRANE (*Field Construction*)
W. D. M. ALLAN (*Shop Manufacture*)

EDITED BY DWIGHT F. JENNINGS

ABSTRACTORS

JOHN E. ADAMS
F. O. ANDEREGG
ROBERT W. ABBETT
ODD ALBERT
A. G. ALEXANDER
S. O. ASPLUND
C. BACHMANN
P. H. BATES
A. A. BRIELMAIER
A. E. BEITLICH
MILES N. CLAIR
C. G. CLAIR
IRA L. COLLIER
M. A. CORBIN
E. L. ERIKSEN
H. FRAUENFELDER
W. I. FREEL
P. J. FREEMAN
H. J. GILKEY
A. T. GOLDBECK
S. C. HOLLISTER
A. J. HOSKIN
F. H. JACKSON
V. P. JENSEN
D. E. LARSON
H. WALTER LEAVITT
L. G. LENHARDT
A. E. LINDAU
ARTHUR R. LORD
H. J. LOVE
P. MCKIM
JOSEPH MARIN
N. D. MITCHELL
REXFORD NEWCOMB
J. C. PEARSON
F. E. RICHART
N. H. ROY
J. H. SHANK
EDMUND SHAW
A. SIZE
T. U. TAYLOR
T. THORVALDSON
G. E. TROXELL
H. S. VAN SCOYOC
STANTON WALKER
G. M. WILLIAMS
C. R. YOUNG
ROY N. YOUNG

MATERIALS

ADMIXTURES

Influence of admixtures of loam in sand upon mechanical properties of portland cement mortars. M. G. JELTSCHANINOFF. *Zement* (Germany), June, 1930, V. 19, No. 24-5, p. 556-60, 580-5.—Experiments concerning influence of loam in sand were subject of comprehensive investigation. Following conclusions were drawn: Loam admixtures in sand are in general unfavorable. Sand may be used containing not more than 2 per cent pure loam. Organic materials in loam are of great importance. Tests must be extended over long period, at least several months. Loam should not be dried before tests. Both tensile and compressive strength must be examined. Question of influence of loam is not entirely solved and must be further studied.—A. E. BEITLICH

Rhenish trass from the neighborhood of Eifel. K. BIEHL. *Ciment* (France), July, 1930, V. 35, No. 7, p. 266-8.—Trass was secured by Romans near Eifel and used in concrete water conduit from that place to Cologne. Parts of the conduit still remain.—F. O. ANDEREGG

AGGREGATES

Application of Trilinear charts to aggregate grading control. THEODORE E. SHEAFER. *Concrete*, April, 1930, V. 36, No. 4, p. 33.—The method of plotting a trilinear chart is explained by example, using four different gradings of sand, indicated by a, b, c and d, the sieve analyses for each being given. The chart is labeled to correspond with the three sieve sizes, No. 14, No. 28 and No. 100. The application of trilinear charts to aggregate grading control is also given in form of a typical example. By carrying in stock three sands of different grading, namely, a coarse sand (C), a sand of medium fineness (M), and a very fine sand (F), the grading of the combined sand (S) can be controlled by selecting the proper proportions of the three sands according to the methods described.—C. BACHMANN

Volcanic slag and similar mineral rocks in the region of the Lake Laach (Germany). OTTO GASSNER. *Zement* (Germany), July, 1930, V. 19, No. 28, 29, p. 658-60, 682-7.—Volcaneous rocks and slags of this region, such as basalt lava, volcaneous slag, tufaceous rocks, pumice and trass are of importance in concrete practice. These materials originate from eruptions of former volcanoes. Their formation and physical properties are described and strength specifications discussed. Special consideration is given to volcaneous slag. Mines are driven into deposits until material collapses. Dump cars transport broken masses to screen which separates them into sizes of 30, 40 and 50 mm. Coarses portion goes through crusher. Conveyer belt delivers material to storage bins. Chemical composition shows great uniformity and no constituents are present, which have unfavorable influence on cement or hardening process. Slag has very good hydraulic properties and shows great resistance to frost. Experiments indicated that concrete with this slag as aggregate also showed great resistance and less decrease in strength when exposed to fires, than concrete which was made with gravel. High heat-insulating properties make it a valuable material for building construction. Data are given for different concrete mixtures and strength properties are compared. A number of further possibilities for use of material are cited. —A. E. BEITLICH

Control and improvement of the grading of sand, gravel and pebbles used as aggregate in concrete. ADOLF JANOUSEK. *Le Ciment* (France),

June, 1930, No. 6, p. 245.—Author gives report of extensive tests to determine approximate volume and surface area of aggregates. Sieves selected were similar to standard American sieves. The pebbles were taken from bed of the Vetava near Prague. Ellipsoids of three axes, slightly angular, were substituted for round and elongated pebbles. It was found that 138 pebbles of 15 to 30 mm. were equivalent in surface area and volume to 218 imaginary spherical pebbles of 15 mm. diameter. As concrete strength depends not only on dimensions of aggregate, but on surface area as well, this is of great importance, particularly in connection with tensile strength of concrete. Parallel tests were made grading the aggregate in accordance with Fuller's curve, Abrams' fineness modulus and using only fine sand and coarse pebbles in the third series. The most instructive mix was a tamped concrete of "moist" consistency with 3.84 liters water, 60 kg. sand and dry pebbles and 9.6 kg. high test portland cement. While the mixes contained equal quantities of mixing water and cement and had the same fineness modulus, their strengths varied greatly. The author urges that sieve analysis be made a part of regular field tests of concrete. To simplify procedure he recommends a set of five sieves of 1, 3, 7, 15 and 30 mm. for the coarser materials and 1, 2, 5, 10 and 20 mm. for the finer materials. The curves obtained resemble the Fuller curve. The allowable discrepancies would be ±5 per cent of the total weight of the material analyzed.—M. A. CORBIN

The economic use of separate aggregates and the automatic regulation of the water addition to obtain a uniform concrete. OSKAR SPETZLER. *Die Bautechnik* (Germany), Feb., 1930, V. 8, No. 9, p. 130-2.—Advantages of separate addition of gravel and sand for manufacture of dense concrete are described. Quality of concrete depends on (1) quality and amount of cement, (2) quality and gradation of aggregates (3) amount of water and (4) good working and finishing of concrete. Amount of water must be changed with varying moisture contents of aggregates. This change can be prevented when sand is saturated with water before entering mixer. Mixing equipment for accurate measuring of materials and production of uniform concrete is described.—A. E. BEITLICH

Effect of soft particles of coarse aggregate on strength and durability of concrete. W. J. EMMONS. *National Sand Gravel Bull.*, June and July, 1930. V. 11, No. 6, p. 9-16, No. 7, p. 9-14.—Report was first presented before the Sixteenth Annual Conference on Highway Engineering, Ann Arbor, Michigan, and published in Proceedings of that conference. It covers results of an investigation carried out by State Highway Laboratory of Michigan to determine effects of certain soft and non-durable particles, occurring locally in gravels, on strength and durability of concrete. Soft particles studied in this investigation included three classifications of sandstone (hard absorbent, intermediate or borderline, and soft) shale, ochre, and a curious light weight, porous, fossiliferous, dolomitic material, colloquially known as floaters. Gravel used as the basis of comparison was hand picked practically free of soft particles. Concrete specimens were made using standard gravel to which was added 0, 2, 3, 5, 10 and 15 per cent of each of the types of soft particles being investigated. Three groups of specimens were made for each percentage and type of soft particle,—a set of specimens consisting of two beams and three cylinders. First group was tested after normal moist air curing for 28 days; second after 25 alternations of freezing and thawing carried out subsequent to 28 days of normal moist air curing; third group has not yet been tested, being held for long-time tests. Author concludes that "after reviewing data here presented there can be little doubt that presence in concrete aggregates of materials studied is injurious. The normal strength of concrete is reduced and liability of deterioration under freezing and thawing conditions is greatly increased. Much of effect of these materials upon

both strength and durability is dependent upon location of particles in structure, and neither in the laboratory nor in the field can this factor be controlled. A far more extensive investigation, involving concretes of different proportions and exposure under many conditions would be necessary to determine, within reasonable range of accuracy, quantitative measures of these effects under service conditions. That such an extended study would be worth while, is doubtful, for the several general types of the undesirable materials are themselves of rather indefinite and variable classification, and not susceptible to accurate definition. In areas where such soft and structurally unsound materials occur, however, this investigation does unmistakably point to the desirability of reducing. to economic minimum, their percentages in coarse aggregate."—STANTON WALKER

CEMENT

Revised procedure for the determination of uncombined lime in portland cement. WILLIAM LERCH and R. H. BOGUE. *Ind. Eng. Chem. Analytical Edition.* July 15, 1930, Vol. 2, No. 3, p. 296-8.—Revised procedure for determination of uncombined lime in portland cements by ammonium acetate titration method is presented. Various factors which bear on precision of test are discussed. A curve is given which shows that percentage average deviation from mean varies with mean value for uncombined lime. The probable errors have been determined and a curve is given which shows probable error of any group of determinations from mean, at any mean uncombined lime content up to 7 per cent.—R. N. YOUNG

Mortars and cements in ancient history. F. GOLDSCHMIDT. *Zement* (Germany), June, 1930, V. 19, No. 23, p. 543-4.—Asphalt was frequently used as building material in countries where it was found; it was good binder and weather resistant. Gypsum and lime were most common mortars. It cannot be determined whether additions of sand were made or if sand, which was found in the analyses was incidentally in raw materials. In dry countries a favorite mortar was clay or loam, mixed with straw, but only suitable for smaller buildings.—A. E. BEITLICH

Rotary kiln calculation. A. B. HELBIG. *Zement* (Germany), June, 1930, V. 19, No. 24, p. 568-9.—Continuation of polemic between author and Hans Bussmeyer on the subject of comparison of heat economy of "Lepol"-kiln and ordinary rotary kiln with waste heat recovery. (c. f. A. B. Helbig, *Zement* (Germany), May, 1930, V. 19, No. 19, p. 440-4 and H. Bussmeyer, *Zement* (Germany), May, 1930, V. 19, No. 22, p. 522-4.)—A. E. BEITLICH

Rotary kiln calculation. HANS BUSSMEYER. *Zement* (Germany), July, 1930, V. 19, No. 29, p. 680.—Last article concerning polemic between author and A. B. Helbig about superiority of "Lepol" kiln over rotary kiln with waste heat recovery. (cf. A. B. Helbig, *Zement* (Germany), May 1930, V. 19, No. 19, p. 440-4 and June 1930, V. 19, No. 24, p. 568-9; Hans Bussmeyer, *Zement*, May 1930, V. 19, No. 22, p. 522-4.)—A. E. BEITLICH

Control of reactions in rotary kiln. *Zement* (Germany), June, 1930, V. 19, No. 23, p. 536.—Description of sampling device designed by W. H. Lacey and Hubert Woods, which enables sampling of clinker at different parts of rotary kiln during burning process. Samples from front end of kiln were taken by means of long iron pipe with attached sample container. Samples from middle and end of kiln were taken through holes which were drilled through shell and lining. Holes were provided with special caps. Arrangement worked very satisfactory. Determinations of free lime and ignition loss showed rate of combination and enabled burning control. (c. f. *Rock Products*, Jan. 1930, No. 2.)—A. E. BEITLICH

About formation of dusting clinker. J. MUNDORF. *Zement* (Germany), June, 1930, V. 19, No. 26, p. 608-9.—A mixture of 40 per cent blast

furnace slag and 60 per cent limestone was burned in a shaft kiln. Coal was mixed with raw mixture. Produced clinker was very satisfactory until recently when product showed very great amount of dusting clinker. Reason for this behavior was an increasing amount of metallic iron up to 8 per cent in slag which lowered fusion point and prevented air from passing through clinker. Uncomplete combination of raw materials resulted. Burning process was under reducing conditions, an amount of 8 per cent of CO was found in the stack gases. Ferric oxide was reduced to FeO and metallic iron. Since Fe and FeO do not combine with CaO an excess of lime was present which fact made conditions worse. After replacing high iron containing slag by good slag, product was of satisfactory quality.—A. E. BEITLICH

Methods of investigating the thermochemistry of cement. W. A. ROTH, *Zement* (Germany), July, 1930, V. 19, No. 27, p. 628-30.—Reactions under investigation are formation of clinker from raw materials and setting and hardening process of cement. Direct calorimetric measurements are impossible to obtain. Heat tones of these reactions can be studied indirectly by determining heat of solution. Best solvent is mixture of 100 parts of hydrochloric acid (20 per cent) and 15 parts of hydrofluoric acid (20 per cent) which dissolves all constituents. Metal container with inner gold lining can be used as calorimeter. Solution can be accelerated by (1) very fine pulverization in order to expose great surface to action of acid, (2) great agitation in calorimeter, (3) higher concentration of the solvent and (4) starting of reaction at higher temperature than room temperature. Experiments were made at 50 and 100° C. Second way to attack this problem is to study heat of formation of end products. Raw materials are burned in calorimeter with paraffin oil as fuel, the heat of combustion of which is determined very accurately. Results obtained directly by this method are very satisfactory. Specific heat of components must be determined in order to calculate results for room temperature or temperatures in cement kiln.—A. E. BEITLICH

Influence of fineness on strength of portland cement. HANS KUHL. *Zement* (Germany), June, 1930, V. 19, No. 26 and 27, p. 604-8, 630-3.—Investigations were carried out to find best particle size of cement to obtain high strength properties. Finest cement portion does not give highest strength. Two cements were separated into 7 fractions from 10 to 60 μ by means of a Gonell air separator. Surface of particles was measured with formula derived by author. Rate of grinding and reaction of cement with water can be expressed by measured surface. Tensile and compressive strength tests with small briquets and cylinders were made after 3 and 7 days. Special care was taken for accurate weighing of cement, sand and water. Saturated gypsum solution was used to prevent quick setting of finest particles. Interesting relations were found between surface and "value-factor," which is calculated from strength data. High strength was obtained with uniform composition and particles of 30 μ size. Mixtures of certain fractions were made and their strength studied. Very fine ground cement can be improved by adding coarser portions within small range; it is not ecomomic to grind cement of uniform size to extreme fineness. Additions of 30 per cent of very coarse cement can be made without considerable loss in strength to a very fine but not uniform cement. The following conclusions were drawn: good cement can be made by grinding material to uniform size, but not too fine, or by grinding to very great fineness and adding coarse cement. Investigation will be continued.—A. E. BEITLICH

Substitution of compression for tension tests as standard tests of cements. *Revue des Mat. de Constr. et des Trav. Publ.*, July, 1930, No. 250, p. 253.—A superior Committee for Standardization was organized in France effective May 1, 1930. Its purpose is to coordinate methods of construction all over France and to bring about standardization. First steps to be taken

by the Committee are official recognition of new types of cement not covered by last standards, the substitution of compression for tension tests, the corresponding readjustment of various types of cement and their official nomenclature. Arguments in favor of substitution of compression tests are presented by R. Feret, Director of the Ponts et Chaussees Laboratory at Boulogne-sur-mer. The proposed limits of compressive strength for portland cement are: 100 kg. per sq. cm. at 7 days and 160 kg. per sq. cm. at 28 days. Strengths for high test portland cement are: 100 kg. per sq. cm. at 2 days; 250 kg. per sq. cm. at 7 days and 320 kg. per sq. cm. at 28 days.—M. A. CORBIN

Spanish specifications of February 25, 1930, for acceptance of cements on public works. *Le Ciment*, July, 1930, No. 7, p. 278.—Separate chapters are devoted to portland cement, high test cements (alumina cements), supercements, slag cements puzzuolan cements and Zumaya (natural) cements. The minimum tensile strength of 1:3 portland cement and standard sand mortar is specified as: 19 kg. per sq. cm. at 7 days (1 day in air, 6 in water) and 23.5 kg. per sq. cm. at 28 days (1 day in air, remainder in water). The minimum compressive strength is specified as: 190 kg. per sq. cm. at 7 days and 280 kg. per sq. cm. at 28 days. For alumina cements the tensile strength required at 24 hr. shall not be less than 28 kg. per sq. cm. and shall attain 60 kg. per sq. cm. at 3 days. The concrete strength tested on 20 cm. cubes of 840 liters gravel, 400 liters sand, 300 kg. cement and 130 liters water shall be greater than: 220 kg. per sq. cm. at 24 hr. and 230 kg. per sq. cm. at 28 days. The tensile strength of 1:3 mortar made with super-cement shall be: 25 kg. per sq. cm. at 3 days; 30 kg. per sq. cm. at 7 days; 38 kg. per sq. cm. at 28 days. The compressive strengths shall be: 250 kg. per sq. cm. at 3 days; 350 kg. per sq. cm. at 7 days and 450 kg. per sq. cm. at 28 days. The concrete strength shall be: 180 kg. per sq. cm. at 2 days and 230 kg. per sq. cm. at 7 days.—M. A. CORBIN

The Spanish cement specifications. C. R. PLATZMANN. *Zement* (Germany), July, 1930, V. 19, No. 30, p. 701-2.—In Feb. 1930, great changes in Spanish standard cement specifications of 1919 were made. New directions include portland cement, high early strength portland cement, alumina cement, blast furnace slag cement, puzzuolan cement and Zumaya cement. Latter is kind of natural cement. Comparison of old and new specifications for chemical composition, fineness, setting time, soundness and strength properties are given.—A. E. BEITLICH

Roller bearings in the cement industry. BELANI. *Zement* (Germany), July, 1930, V. 19, No. 28, p. 654-7.—Author discusses different types of roller- and ball-bearings which can be used in cement industry. Economic point of view is given. Advantages of certain types for special purposes are described. —A. E. BEITLICH

Experiments with mixed cements consisting of high alumina cement and ground basic blast furnace slag. WILLIAM PETRY. *Zement* (Germany), July, 1930, V. 19, No. 29, p. 674-8.—Mixtures were made from high alumina cement "Alca" and blast furnace slag in following proportions: cement : slag : sand, 1:0:3; ¾:¼:3; ½:½:3, and ¼:¾:3. Compressive and tensile strength tests were made after 3, 7 and 28 days. Results showed that no great decrease in tensile strength takes place when one half of cement is replaced by slag. This mixture gives compressive strength which is much higher than strength which is demanded by standard specifications. Not more than half of cement should be replaced by slag. Additional tests were carried out in order to investigate action of different salt solutions, such as magnesium sulphate (5 per cent), sodium sulphate (4 per cent), sulphuric acid (1 per cent), acetic acid (1 per cent) and ammonium sulphate (5 per cent). General appearance and tensile strength after 15 months storage of test pieces, which were immersed in these solutions, showed that action of first

four solutions is considerable lower when one half of cement is replaced by slag. Only ammonium sulphate solution produced great deterioration in every case.—A. E. BEITLICH

The heat in the finishing mill and the setting time of cements. HEISER. *Zement* (Germany), July, 1930, V. 19, No. 29, p. 679-80.—Discussion of research work done by K. Koyanagi (*Zement* (Germany), May 1930, V. 19, No. 20.) concerning influence of heat during grinding process of cement on its setting time. Based on own investigations author comes in general to different conclusions and claims that quick setting cement is not necessarily produced when temperature in finishing mill is very high. With temperatures up to 100° C. he still obtained normal setting clinker.—A. E. BEITLICH

The sealing of rotary kilns, dryers and similar equipment. ERICH SCHIRM. *Zement* (Germany), June-July, 1930, V. 19, No. 23, 24, 26 and 27, p. 545-8, 570-2, 618-20, 642-4.—Several different types of seals are described. Discussion shows which types are suitable for special purposes. All advantages and disadvantages are illustrated and directions are given to prevent excessive wear. Seventeen photographs are reproduced.—A. E. BEITLICH

Experiments with a compeb mill using special steel fillings. OTTO FREY and MOSCHITZ. *Zement* (Germany), July, 1930, V. 19, No. 28, p. 652-4.—Experiments were made with a three-compartment compeb mill to increase efficiency by studying best combination and weight of various steel fillings with different shapes. Best results were obtained with filling of steel balls in first compartment, special patented "Kordt-balls" in second and steel cubes with small steel balls in third compartment. With usual filling of steel balls in first and second and "Cylpeps" in third compartment 12,500 kg. material was ground in one hour to fineness of 2.5-4 per cent residue on 4900 mesh sieve. With new filling 15,000 kg. was ground in one hour to fineness of 0.5 per cent residue on 4900 mesh sieve. Power consumption was 540 H. P. instead of 520 H. P. Material was clinker for production of special high early strength cement.—A. E. BEITLICH

Scientific research. *Structural Engineer* (England), August, 1930, V. 8, No. 8, p. 302-3.—The use of "hot cement," meaning cement which still retains much of frictional heat of grinding, has been found by Building Research Department (Bulletin No. 7) to have unimportant effects when used "under conditions likely to be found in a job." Tests reported in Building Research Special Report No. 15 are said to prove that coal residues are definitely unsuitable for use as aggregates in concrete reinforced by or in contact with steel. Sulphur contents of materials are considered to be prime cause of corrosion, and porosity and permeability to be of minor significance.—V. P. JENSEN

Production of Norwegian cement industry. *Zement*, (Germany) May, 1930, V. 19, No. 22, p. 525.—Data are given which show progress in production of cement in Norway during last 20 years.—A. E. BEITLICH

Studies of the behavior of cement mortars in hot water. Experiments made at the laboratory for testing materials of the Technische Hochschule in Stuttgart (Germany) during the years 1928 and 1929. "Versuche ueber das Verhalten von Zement-moertel in heissem Wasser." OTTO GRAF. German committee for reinforced concrete, publication No. 62. Willhem Ernst und Sohn, Berlin 1930, R. M. 4.30. Reviewed in *Der Bauingenieur* (Germany), June 1930, V. 11, No. 24, p. 427.—Book describes investigations of behavior of mortars exposed to water of different temperatures and under different conditions. Four kinds of cement, two

portland cements, one high early strength portland cement and one high alumina cement were tested at 20, 50 and 90° C. Compressive and tensile strength of 1:3 and 1:6 mixtures were studied. Behavior of cements was very different. Loss in strength is discussed. Steam of 50° C. has improving effect on samples while water storage at 50° C. reduces strength. Author derives theory about setting of cement and its solution process.—A. E. BEITLICH

Burning of cement on a chain grate. ERICH SCHIRM. *Tonind. Ztg.* (Germany), July 24, 1930, V. 54, No. 59, p. 978-81.—The application of chain grate principle to burning cement and lime to reduce the fuel requirements. Trouble is that clinker sinters to the grate and Lellep has proposed (German pat. 466,298) to use the chain grate for calcining and rotary kiln for clinkering. Result is much saving in space. It is claimed that the chain grate makes effective dust and heat remover from the gases. Average requirement of less than 2000 B. T. U. per lb. of clinker is claimed.—F. O. ANDEREGG

Apparatus for laboratory control of fineness of cements and description of several experiments carried out with this equipment. A. H. M. ANDREASEN and J. J. V. LUNDBERG. *Zement* (Germany), July, 1930, V. 19, No. 30-31, p. 698-701,7 25-7.—Description of apparatus to determine fineness of cement in which sample is mixed with liquid media. Ethylene-glycol was found to be best liquid for this purpose which gives suspension free of coagulation without peptonizator. Its specific gravity at 20° C. is 1.112 and its viscosity at 20° C. is 0.214 which covers correct range for particles from 5 to 100 μ. Experiments were carried out with (1) two portland cements, (2) one blast furnace slag cement, (3) one French high alumina cement, (4) calcined magnesite and (5) stucco. Apparatus allows continuous taking of samples and gives results of high accuracy. Blast furnace slag cement shows some tendency to coagulate but gives good results. Strong coagulation was found in case of alumina cement which could be prevented by addition of cobalti chloride (0.005 mol per liter). Magnesite gave fairly good results in pure glycol. Mixture of 50 volume per cent absolute alcohol and 50 volume per cent glycol with specific gravity of 0.964 and viscosity of 0.0497 at 20° C. and an addition of potassium citrate (0.005 mol per liter) was used for stucco. Tables showing results obtained and several references are given.—A. E. BEITLICH

New means for protection of concrete against acids and aggressive waters. *Chemiker Zeitung* (Germany), Apr., 1930, V. 54, No. 27, p. 259-60.—Description of properties of number of new water-glass cements. It is claimed that they are acid proof and can be manufactured with quick and slow setting properties. Hardening is not influenced by any weather conditions and can also take place, when no air is present. Good cementing material for bricks of acidproof tanks, acid towers and sewage pipes. Temperatures up to 800° C. do not affect cement. It can be used with advantage for linings of concrete structures and foundations exposed to acid sprays or drops.—A. E. BEITLICH

Obtaining finely ground raw materials for cement. J. GUERIN. *Ciment.* (France), July, 1930, V. 35, No. 7, p. 262-6.—Rapid recirculation combined with filtration gives best results.—F. O. ANDEREGG

The reliability and predictive value of short time tension tests of portland cement. H. WALTER LEAVITT and JOHN W. GOWEN. *Maine Technology Exp. Sta. Bull. No. 25*, June, 1930, V. 16, No. 2, 8 pages.—Increased use of portland cement and advent of so-called super-cements have

caused highway engineers to demand more rapid tests for mortar strength than formerly. It has been shown that 7-day tensile strength tests will give fairly accurate prediction of 28-day tensile strength of portland cement. (c. f. "The prediction of 28-day tensile strength of portland cements from their 7-day strengths" by John W. Gowen and H. Walter Leavitt, Bulletin No. 15, pp. 1-14, May, 1926. Also "Relation of 7-day to 28-day compressive strength of mortar and concrete" by John W. Gowen and H. Walter Leavitt, Bulletin No. 17, pp. 1-13, Maine Technology Experiment Station, October, 1926.) This paper gives data on 150 samples of portland cement of many different brands as received at the Testing Laboratory for the latter half of the year 1929. It was shown that the variability of any briquet from a series of three made from the same batch does not change much either in a 1-day, 3-day, 7-day or 28-day tests. This conclusion was derived by a statistical study of the data in hand. The predictive value of the 1-day, 3-day and 7-day tests was determined and the following coefficients derived: 1-day, 3-day and 7-day tension vs. 28-day tension give correlation coefficients of 0.322 ± 0.049, 0.395 ± 0.047 and 0.734 ± 0.020 respectively. Previous study in 1926 showed 7-day tension vs. 28-day tension giving a correlation coefficient 0.654 ± 0.015. Higher coefficient obtained in 1930 is partly explained by better quality of cements now on market and partly by better technique in methods of testing. The conclusions were: (1) Inter-relation of one briquet with another in 1-day, 3-day, 7-day, and 28-day tests are relatively high. (2) The 7-day tension tests give much more reliable prediction of 28-day tension tests than 1-day or 3-day tension tests. (3) Data should be produced to show superiority of any other age period over 7-day period before discarding old preliminary test age (7-day) period.—H. WALTER LEAVITT

New 2,000-bbl. wet-process cement plant nears completion in Southwest. *Pit and Quarry*, July 2, 1930, V. 20, No. 7, p. 47-50 and 54.—New plant of American Portland Cement Co. at Foreman, Ark., is straight-line layout with provision for doubling capacity. Rock is chalky limestone of uniform quality. Quarry cars will be hauled by locomotives to trestle over hopper. Rock will be crushed to ½-in. size and coveyed to steel bins or diverted to open storage. Clay will be obtained from neighboring pit. Clay-slip from concrete washmill will be pumped to steel storage tank and thence it will pass to raw grinding tube-mill with rock. Ground material will pass to agitated slurry slump, and thence to storage tanks equipped with agitators. From these tanks, slurry will be pumped to correcting basins and thence to kiln feeder. Kiln is 11 ft. 3 in. in diam. and 300 ft. long, electrically welded throughout, with four tires. Clinker will pass to a vertical cooler with sloping shelves and sprays of water. Cement will be pumped pneumatically to 12 storage silos of a combined capacity of 100,000 bbl., from whence it will be pumped to packhouse containing three packers. 16 illustrations.—A. J. HOSKIN

Cement plant's capacity can be trebled without stopping operation. *Pit and Quarry*, July 2, 1930, V. 20, No. 7, p. 51-53.—At Rosedale, N. Y., plant of Century Cement Corp., rock occurs in two beds separated by 15 ft. of impure limestone. Excavation is by room-and-pillar underground method, in each bed. Mined rock from two sets of workings is kept separate and is hauled to trestle above eight vertical kilns which utilize buckwheat anthracite fuel. Clinker is drawn, hand-picked, crushed to ¾-in., elevated, and deposited in three bins—one bin for the burned light-colored rock, one for the dark rock, and one for occasional needs. The clinker is next taken by an aerial tramway, to top of finishing plant. Tram buckets are loaded and unloaded automatically. Clinker is stored in three steel bins, then withdrawn, weighed, and fed to grinding mill. Pulverized product is air-collected into bin over final grinding tube-mill. Natural cement goes to four storage silos and

enroute to packers, it passes vibrating screens, the oversize returning to the finish tube-mill.—A. J. HOSKIN

Arkansas' only producing cement plant embodies simplicity and safety. W. E. TRAUFFER. *Pit and Quarry*, July 2, 1930, v. 20, No. 7, p. 35-46, 47 illustrations.—New plant of Arkansas Portland Cement Co. at Okay started operation last fall. Mill construction began in Nov., 1928. Crushing began June 18, 1929, and first shipment of finished cement was made Oct. 2, 1929, 125 carloads. There are only four principal pieces of machinery in the plant: a No. 60 swinghammer crusher, two Compeb mills, and 300-ft. rotary kiln. Raw materials are from bed of Austin chalk and overlying bed of argillaceous loam. Blasted rock and clay are hauled to plant in steel side-dump cars. Quarry-haulage system is merely temporary, and is, eventually, to be converted into electric, central-tower-control system. Single crusher can reduce from 35-in. to 1-in. Stone and clay are excavated on alternate days. Entire storage space is divided into four compartments with concrete walls. Gypsum is unloaded from box cars by power scraper to conveyor directly to storage. Silica sand, required to maintain correct SiO_2 content, is unloaded from gondola cars by same power scraper and conveyor. Rock, clay and sand discharge through plate feeder to pugmill. This, discharges to 3-compartment raw-grinding mill which uses steel balls, and resulting slurry is handled by pumps to any of six 400-bbl. concrete batch tanks, equipped with mechanical and air agitation. Slurry, in proper proportion, is pumped into concrete mixing tank, thence to slurry-storage tank, also equipped with mechanical and air agitator. Slurry moisture is maintained at 47 per cent. Kiln is 11½ ft. in diam. and 300 ft. long, and uses natural gas fuel. Slurry filter is being installed to increase kiln's capacity from 2,400 bbl. to 3,000 bbl. per day. Slurry cake will be discharged from filter to belt conveyor discharging to feeder, to kiln. Clinker drops from the kiln to steel dragchain, discharging to iron bucket elevator, that handles clinker to storage. Finish mill is 3-compartment, compeb mill with a peripheral screen and pick-up pipes between the first and second compartments. Ground cement is fed to pneumatic pumps by which cement is carried through 5-in. line to any of 12 storage silos, having total capacity of 230,000 bbl. Exbiners, screw conveyors and bucket elevators deliver cement to packhouse. Article gives details of power and transmission equipment, and describes laboratories, offices, shops and village with water supply and sewage disposal.—A. J. HOSKIN

PROPERTIES OF CONCRETE

Protecting reinforced concrete against corrosive solutions. HANS VÄTH. *Tonind. Ztg.* (Germany), 1930, V. 54, No. 61, p. 1010-1, No. 62, p. 1026-8.—Foundation for a coke plant was built of aluminous cement (Alca) in contact with $CaSO_4$ soln. Above ground it began to deteriorate within 6 months. Test specimens proportioned 1:3, in water were in perfect shape and showed increased strength after 142 days, but specimens of mixes 1:6 and 1:10 suffered cracking and loss of strength. When placed in 10 per cent $MgSO_4$ soln. specimens of 1:3 and 1:6 seemed in good condition but were weaker after 131 days. The 1:10 specimens lost no strength, although they became white. When stored in ground water from the coke plant the 1:3 and 1:6 specimens appeared in good shape but lost strength, while the 1:10 deteriorated badly. When planted at the building a 1:5.7 specimen 4 by 4 by 22 in. bar cracked badly in 120 days. Similar specimens of high early strength portland and of slag cements were in good shape at end of same period.—F. O. ANDEREGG

The structure of mortar and concrete. "Der Aufbau des Moertels und des Betons." OTTO GRAF. 3rd edition, 1930, Julius Springer, Berlin W9 (Germany), R. M. 17.50. Reviewed in *Zement* (Germany), June, 1930, V. 19, No. 25, p. 596.—This enlarged edition deals with compressive strength, flexural strength, weather resistance, water permeability, shrinkage and expansion of cements and mortars. Special consideration is given to concrete made with volcanic slags and pumice. Experiments with mortars of different compositions are described. Directions are given for concrete control on the job.—A. E. BEITLICH

The concrete brick. "Der Betonwerkstein." 1930. Editor: Bund der Deutschen Betonwerke E. V. Berlin NW6 (Germany). Reviewed in *Zement* (Germany), June, 1930, V. 19, No. 24, p. 572—Properties of concrete bricks and their application in practice are described. Directions are given for their valuation.—A. E. BEITLICH

The yield of certain concrete mixes. A. G. DARWIN. *Concrete*, July, 1930, V. 37, No. 1, p. 29.—Since cement is usually most costly ingredient of concrete mix, it is desirable to so proportion aggregate constituents that for given required strength, range of workability and other factors, the minimum cement factor obtains. Following are some general conclusions that may be drawn from yield study of Moscow crushed basalt rock and Spokane sand concrete, but only under laboratory conditions. (1) For given water-cement ratios of 0.85, 0.90, and 0.95, yield decreases at nearly uniform rate with increase in dry-rodded proportion of sand to rock. (2) For given proportion of sand to rock by dry-rodded volumes, yield increases as water-cement ratio increases. (3) For a given proportion of sand to rock the yield increases as strength decreases.—C. BACHMANN

Miscellaneous concrete construction practices. K. GOSLICH. *Zement* (Germany), June, 1930, V. 19, No. 24, p. 567-8.—Disintegration of concrete is caused by water containing sulphuric acid or sulphates, especially the magnesium salt. New experiments seem to prove erroneous the conclusion that cements which are high in lime are more easily attacked by such waters. Most important factor is density of concrete which can be obtained by expensive rich mixtures or by carefully proportioned aggregates. Concrete pieces which are partly immersed in water show greatest corrosion at line between water and air. Capillarity of concrete and concentration of salts by evaporation are to blame for this effect. Paraffin and asphalt or mixtures of asphalt and tar are suggested for protection of concrete pipes.—A. E. BEITLICH

Solution phenomena of concrete. RICHARD GRUN. *Der Bauingenieur* (Germany), June, 1930, V. 11, No. 26, p. 451-4.—Solution of concrete can take place in two different ways, (1) by water which is poor in carbon dioxide by direct solution of lime, or (2) by water rich in carbon dioxide. In second case, lime is converted to calcium carbonate, then to soluble calcium bicarbonate and finally back to calcium carbonate which appears in voids and on surface of concrete. These reactions cause loss in strength and deterioration of concrete. Such action can be prevented by making dense concrete which does not allow penetration of water. Use of cement which is low in lime and addition of certain admixtures are suggested for concrete protection.—A. E. BEITLICH

Winter-laid 10,000-lb. concrete on Chicago viaduct. ARTHUR R. LORD. *Eng. News Record*, Aug. 14, 1930, V. 105, No. 7, p. 258. During the construction of new bascule bridge across Chicago River at Wabash Ave. in Chicago, a

large area of concrete deck slab and several supporting columns were removed from Wacker Drive. Chunks of concrete from the debris were sawed into 3x3-in. cubes for testing. Tests showed an average strength for cubes of 11,400 lb. per sq. in. Equivalent cylinder strength is considered to be about 85 per cent of this value. Cylinder tests at 28 days showed a strength of 2,620 lb. per sq. in. On this basis, strengths at 46 months are over three times those at 28 days, and over 2½ times those that would be expected at 28 days in summer weather for this mix and water-cement ratio. This concrete was made with seven sacks of cement, 14 cu. ft. of Beloit sand, and 22 cu. ft. of crushed limestone. Water-cement ratio was 6.5 gal. of water per sack of cement. During placing, the temperature of air above the slab varied from zero to slightly above freezing. All materials were heated to give temperatures in fresh concrete of about 80° F. at mixer, about 60° at forms and about 35° to 40° at upper surface of slab by the time it had hardened sufficiently for workmen to cover it with straw. Air beneath the slab, heated by salamanders, varied from 55° to 85° F. during curing period of seven days. Under the straw, temperatures at the surface of the slab were above 50° F. during the week.—D. E. LARSON

Shrinkage of concrete as a factor in compressive steel stress. (See ENGINEERING DESIGN—Miscellaneous.)

Dock and harbor construction in British colonies. (See ENGINEERING DESIGN—Miscellaneous.)

Vibrated concrete. (See FIELD CONSTRUCTION—Miscellaneous.)

Effect of soft particles of coarse aggregate on strength and durability of concrete. (See MATERIALS—Aggregates.)

Studies of behavior of cement mortars in hot water. (See MATERIALS—Cement.)

ENGINEERING DESIGN

BRIDGES

International contest for construction of bridge over Lake Maelar in Stockholm (Sweden). *Zement* (Germany), July, 1930, V. 19, No. 30, p. 712-4.—First prize was given to plans by Prof. F. von Emperger, Vienna for reinforced concrete bridge consisting of two arches with span of 198 m. each. Roadway is 17.50 m. wide with two 2.25 m. wide sidewalks and consists of 5 cm. thick asphalt slabs. Dimensions of structure and details of reinforcements are given.—A. E. BEITLICH

Concrete arch Mississippi bridge at Minneapolis. *Eng. New Record*, July 10, 1930, V. 105, No. 2, p. 49-50.—Two reinforced-concrete rib-arch spans of 265½ ft. in the clear form the channel portion of the new Cedar Ave. bridge across Mississippi River at Minneapolis, Minn. They have rise of 90.5 ft. and are located on tangent of 611 ft., crossing river on skew. Three flanking arch spans on west side and two on east side are of 93 ft. span and are on curves of 5 deg. 41 min. and 5 deg. 18 min. respectively. All arch spans have two ribs 12 ft. wide and 24 ft. apart in clear, with thickness for main spans of 3.5 ft. at crown and 7.5 ft. at haunches. A three-center curve having radii of 154 and 48.5 ft. is used for intrados, and a curve having a single radius of 167.5 ft. is used for extrados. Each main span rib is reinforced with five steel ribs 31½ in. deep at crown. Chords are composed of pairs of angles 3½ x 3½ x ⅜ in. and web members of smaller angles. Each rib in side spans

is reinforced with sixteen longitudinal bars top and bottom tied together with loop bars 4 ft. apart. Footings for three river piers are 30 x 54 ft. At east and center piers they rest on sandstone bedrock while west pier footings are supported on 180 piles 32 to 42 ft. long driven into gravel formations and spaced 3 ft. c. to c. both ways. Transverse spandrel walls practically full width of arch ribs, and spaced 13 ft. 4½ in. c. to c. in the main spans and 12 ft. in the flanking spans, have cantilever brackets for sidewalls and carry pairs of transverse 24-in. I-beams which support 12-in. reinforced-concrete deck slabs.—D. E. LARSON

Design of road bridges. C. S. CHETTOE. *Roads and Rd. Constr.* (England), June 2, 1930, V. 8, No. 90, p. 181.—Culverts. Except where there are rock foundations, culverts usually have inverts. Total foundation pressure is equal to vertical component of forces acting on culvert top, plus weight of culvert and if necessary, water, when it is running full. On mass concrete or rock foundation, pressure would be either concentrated under walls, or distributed along whole base, with maximum at centre, according to whether moments due to forces caused convexity or concavity upwards, in invert. On yielding clay, pressure tends to become uniform for all conditions of loading. Culvert is designed as two fixed elastic arches with abutments at centre of top and invert, where no angular displacement is assumed. Horizontal thrust on invert is equal to actual forces on one side of culvert less horizontal thrust at crown. Shear at sharp bends may be appreciable. Ideal shape is a circle. No allowance need be made for temperature shrinkage, or rib shortening. Formulae are given for the necessary bending moments. Rectangular culvert is most suitable for spans up to 8 or 10 ft. on account of simplicity of shuttering and steel fixing, although it is not most economical shape for material. Large culverts are usually semi-elliptical with straight or slightly rounded inverts, and sometimes, extended invert ends. For culverts passing beneath deep bank, on compressible soil, special longitudinal reinforcement may be required either in deck and invert, or at four corners, to take up positive bending moments. Vertical reinforcement may need to be increased to take shear.—JOHN E. ADAMS

Design of road bridges. C. S. CHETTOE. *Roads and Rd. Constr.* (England), July 1, 1930, V. 8, No. 91, p. 217.—Abutments: If filling is not to be completed until after decking is in position, final stresses only need be considered; otherwise abutment wall should be designed to act as retaining wall during construction, and to take final live and dead loads in addition. Downward forces on abutment are weight W' and reaction from girders, W''. The horizontal forces will be P, due to earth pressure and surcharge and $\pm W''$ x m, where m is the coefficient of friction between girder and bearing plate. Abutments should be able to withstand any movement due to lengthening or shortening of girders. Mass concrete girders should have thickness of 0.35 x height at base and be relatively thicker at top than ordinary retaining walls. For spans up to 20 ft. rolled steel joists are allowed to rest directly on smooth concrete without provision for expansion. Bearing plates are usually provided for built-up girders, up to 40 ft., girders from 40 to 60 ft. span usually are carried on cast iron or steel plain bearings arranged for sliding at one. When rein. conc. girders are used no expansion bearings are necessary up to 35 ft. span, particularly if carried on piles. Spans up to 50 ft. may have felt bearings, while larger spans have two outer and two inner plates of steel and copper respectively. In lighter, reinforced concrete abutments having counterforts and sill beams, which take the decking beams, the wall prevents sill beams from deflecting and taking much of load. Curtain walls which span horizontally, are designed for moments of $\frac{pl^2}{12}$ at counterforts, and $\frac{pl^2}{24}$ at mid

span. The end spans are designed for $\frac{pl^2}{10}$. Distribution steel must be provided at sill and junction with foundation, to avoid cracks due to reverse moments. Counterforts are designed as ordinary retaining walls and should be checked for safety before and after decking is on, and for full live loads. For arch abutments, of mass concrete, final thrust should approximately bisect bearing surface and be normal to it. The top of arch abutment must never be finished off horizontally or it will have no shear resistance. Abutments may be cellular with a sill beam. Active earth pressure, only, is allowed for except where abutments are carried against hard virgin soil, or rock. In poor ground, short cantilevered end-spans are economical. Piers: In case of adjacent arch spans, resultant thrust at base should lie within middle third, worst case being when one span is fully loaded, and other unloaded. If A is free horizontal deflection due to maximum difference of horizontal thrust at pier top, and B horizontal movement of springings if free to slide on pier top, due to the same force, then the horizontal force taken by pier will be approximately $\frac{B}{A + B}$ and the rest will be taken by the arches.—JOHN E. ADAMS

Exhibition of new concrete bridges built in Bavaria (Germany). A. ZENNS. *Zement* (Germany), July, 1930, V. 19, No. 28, p. 660-3.—Design and construction of a number of reinforced concrete arch-, frame- and girder-bridges are shown by several photographs and drawings.—A. E. BEITLICH

Arch bridge near Echelsbach (Germany). (See FIELD CONSTRUCTION —Bridges.)

BUILDINGS

Tables for construction technique. "Bautechnische Tabellen." KARL-JOHANN HOCHREUTER. 1930, Gustav Winters, Bremen (Germany). Reviewed in *Zement* (Germany), July, 1930, V. 19, No. 30, p. 714.—Book contains tables for mathematical calculations of static and dynamic stresses in steel and reinforced concrete construction. Directions for erection of such structures are given. Tables are valuable aid to contractor and designer.—A. E. BEITLICH

Warehouse in Minden (Germany). *Zement* (Germany), June, 1930, V. 19, No. 23, p. 538-9.—A storage house with a capacity of 6000 tons wheat was built in reinforced concrete skeleton construction. Four floors, designed for live load of 2000 kg./m², were constructed with slab-girders. Eight bins, 13 m. high and 3.80 m. x 2.60 m. wide, are on north side. Grain elevators, mill equipment and offices are located in building.—A. E. BEITLICH

Tests on concrete frames simulate effects of earthquake action on buildings. *Eng. News Record*, July 10, 1930, V. 105, No. 2, p. 55.—This article, which is an abstract of paper read before recent international engineering congress in Japan by Mikishi Abe, consulting engineer of Tokyo, presents conclusions from tests made to study action of rectangular reinforced concrete frames under repeated horizontal load. In these tests, made at University of Illinois, periods of free or natural vibration of reinforced concrete frames were measured in order to compare them with known formulas. Four main points considered were: (1) Behavior of frames under horizontal loads repeated many thousand times. (2) Free vibration periods before and after cracking of frames. (3) Effect of construction joints upon horizontal deflection under repeated static horizontal loads. (4) Methods of improvement in design and construction. Mr. Abe stated that the results were in fair agreement with the analyses. Several of his conclusions are summarized as follows: (1) Observed stresses in frames were not increased by

repeated application at low loads. Under high loads, stresses were slightly increased, but intensity was well within computed values. (2) Periods of free vibration of test frames, measured by aid of motion photographs, were about 0.03 second, before any cracks had developed. After cracks had developed, periods were about 0.04 second. From these results, it is argued that there is small possibility of synchronizing natural vibrations of a building with vibrations of a great earthquake after the composing members have been cracked. (3) Horizontal deflections of frame with ordinary construction joints at feet of columns were almost equal to those of frame with no such joints, but were much larger than where dowels were used. (4) Use of large haunches at end of beam was apparently inadvisable because many small cracks appeared in haunches. Bending stresses at top of the column were much reduced, while stress at bottom was not reduced by use of large haunches. (5) Construction joint in beam is not objectionable if properly built although cracks due to vibration tend to follow joint.—D. E. LARSON

Design and construction of modern factory in reinforced concrete. A. W. LEGAT. *Structural Engineer* (England). May, 1930, V. 8, No. 5, p. 178-190.—Soap factory requiring 4066 cu. yds. of concrete is described in detail from selection of site and general dimensions to details of design, materials, and methods of construction. Building features reinforced concrete loading bays, milling bay including hoppers, and in general reinforced concrete for the entire building with two exceptions, first, where steel was used for roof trusses and materials storage tanks, and second, where brick was employed for sleeper walls and temporary end paneling.—V. P. JENSEN

New structures of paper plant in Scheufelen near Oberlenningen i. Wuert. (Germany). A. WEGENAST. *Zement* (Germany), June, 1930, V. 19, No. 24, p. 565-7.—Several new buildings were erected in enlarging program of big paper plant. One building which serves as connecting link between old buildings is 23.65 m. long, 11.75 m. wide and 31 m. high. It contains main stairway, washrooms and several rooms for general purposes. Entire building and stairway is constructed of reinforced concrete. Main building, which houses machinery and material storage is 5-story structure with two rows of center columns spaced 5.50 m. apart. Connecting beams have span of 7.50 and 9.65 m. High early strength portland cement was used for their construction. Ceilings are "Remy" ceilings designed for live load of 1000 kg./m.^{2} Third building shows interesting ceiling construction. Area of 2960 m^2 is covered with only eight columns. High quality iron-portland cement was used. Transformer building is 49.50 m. long, 6.00 m. wide and 4.30 m. high.—A. E. BEITLICH

DAM

Cobble Mountain dam of Springfield, Mass. JAMES B. PORTER. *Eng. and Con.*, July, 1930, p. 255-257.—Highest hydraulic fill dam in the world will make use of concrete cut-off walls in bottom of dam. These walls extend up slopes on each side. Concrete arched wall 14 ft. wide on top, with vertical upstream face and ¼ to 1 downstream face, and with 100 ft. radius is to be at downstream toe of hydraulic fill dam. Spillway will care for 400 second feet per square mile of watershed. Reinforced concrete arch bridge will be built over spillway and will carry highway that goes over top of dam.—N. H. ROY

MISCELLANEOUS

Reinforced concrete design simplified. JAMES R. GRIFFITH. *Concrete.* June, 1930, p. 45-47.—Design of long columns, h/R greater than 50, according to A. C. I. specifications is greatly simplified by use of a nomographic chart containing all necessary quantities.—N. H. ROY

Reinforced concrete design simplified. JAMES R. GRIFFITH. *Concrete*, July, 1930, V. 37, No. 1, p. 43-46.—Prof. Griffith has constructed charts to simplify design of tied columns according to A. C. I. Code. Three quantities are given in charts, area of longitudinal steel, total column load, and size of square columns for 2000 and 3000 pound concrete. Comparison is made with Joint Committee requirements. A. C. I. Code is the more liberal of the two. —N. H. ROY

Method of calculating strength of steel beams encased in concrete. O. H. MENGERING. *Concrete*, June, 1930, V. 36, No. 6, pp. 35-37.—Rational method of analysis of composite steel and concrete beam sections is presented. Author gives methods of obtaining areas and statical moments and location of neutral axis of compound sections. Expressions for K, kd, and b, width of member, are set up for balanced section. Sufficient material, concrete or steel, is supplied to balance tensile steel area. Expressions for moments of inertia of compound and balanced sections are also given. Likewise equations for moment of inertia and width of stem of tee-beams are given. Shear, bond, deflections and resisting moments are discussed and typical problems solved. Width of beams is found to vary with grade of concrete and is inversely proportional to value of n, ratio of moduli of elasticity of steel and concrete. For the section chosen, the resisting moment was increased about 13 per cent by encasing in concrete. The center deflection of simply supported beam of the section used was from 36 to 27.5 per cent less for the concrete encased beam than for steel section alone.—N. H. ROY

Shrinkage of concrete as a factor in compressive steel stress. *Eng. and Con.*, June, 1930, p. 234-236.—Prof. Maney's discussion and conclusions, as presented to Western Society of Engineers April 7, are summarized and two general conclusions drawn regarding tremendous increase in compressive steel stress in a beam under sustained loading over period of two months. Plastic flow is negligible factor. Shrinkage is controlling factor. Amount and effect of shrinkage are predictable. A law regarding shrinkage has been evaluated for benefit of designers. Amount of shrinkage was found to be controlled by percentage by volume of cement paste and quality or water-cement ratio of paste. Data from experiments is given partly by curves. Measured stresses in compressive steel after 40 days of continuous loading were found to be approximately 2½ times the calculated stresses. Deformations in concrete at compressive surface were very high. Flow of concrete around reinforcing rods took place without damage to bond. A. C. I. Column Code and possibilities for its improvement are discussed at length. Specifications nf_c for compressive steel holds only for load changes; for time loading it is not sufficient. For ordinary case nf_c is only a small part of total compressive steel stress. It is predicted that compressive steel with high elastic limit and controlled shrinkage will feature changes about to take place in reinforced-concrete design.—N. H. ROY

Steel beams much stronger when encased in concrete. F. A. RANDALL. (Report of Committee of the Western Society of Engineers), *Concrete*, June, 1930, V. 36, No. 6, p. 34.—Tests made at plant of American Bridge Co., at Gary, Indiana, on floor framing encased in concrete, were completed and reported upon on May 12. Floor system was described in *Concrete*, Nov., 1929, p. 24. Deflections and deformations were measured on steel members, which were then encased in concrete and readings taken again after 28 days. Loads up to twice dead plus design live loads were applied. Test results were compared with usual design computations. Tensile stress in bottom flange of steel beams was greater than compressive stress in upper flange, due to concrete in upper part of member taking compressive stress,

whereas concrete in lower part of member probably did not take any tensile stress. Thus neutral axis of composite member was in effect raised and tensile stress was lower than it would have been in an unencased member. Measured stresses in tension flanges of fully loaded beams averaged 56 per cent of so-called computed stresses for cinder concrete panels and 57 per cent for gravel concrete panels. "Computed stress" denotes theoretical stress obtained by usual design methods, considering that steel section carries entire load. Committee recommends working stress of 24,000 lbs. per sq. in. be allowed on steel section when it is encased in manner similar to that of tests and using materials of like quality on I-beams and girders up to 24 in. in depth. Full committee report is contained in the June Journal of the Western Society of Engineers.—N. H. ROY

The steel requirement for reinforced concrete beams. KURT BERNHARD. *Zement* (Germany), June-July, 1930, V. 19, No. 25, 27, 28, 29, p. 591-5, 637-40, 663-6, 688-90.—Author illustrates influence of "steel-coefficient" for calculation of reinforced concrete beams as this was done for concrete slabs in previous article (*Zement* (Germany), April-May, 1930, V. 19, No. 16-20, p. 379-83, 405-9, 447-52, 474-8). Examples of practice showing steel requirements under all possible conditions of stresses are cited. Formulas and calculations are given for single beams and panel construction.—A. E. BEITLICH

Water power stations. "Wasserkraftanlagen." FELIX BUNDSCHU. 1929, 130 pp. Walter de Gruyter, Berlin, R. M. 3.00. Reviewed in *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereins* (Austria), April, 1930, V. 82, No. 17-18, p. 156.—Book gives (1) general directions for design and construction of water power stations, (2) describes locks and breakwater and (3) water pressure pipe construction and laying.—A. E. BEITLICH

Calculation of masses in reinforced concrete construction on theoretical basis. "Die Massenberechnung im Eisenbetonbau auf theoretischer Grundlage." FRITZ BUECHI. 1929, 139 pp. Wilhelm Ernst und Sohn, Berlin, R. M. 5.60. Reviewed in *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereins* (Austria), May, 1930, V. 82, No. 21-22, p. 188.—Book discusses analyses of calculations for masses in concrete construction and gives formulas for calculation of all kinds of cross-sections. Several examples of practice are cited and numerous tables are given.—A. E. BEITLICH

Pile driving calculations with notes on driving forces and ground resistance. A. HILEY. *Structural Engineer* (England). July, 1930, Vol. 8, No. 7, p. 246-259 and August, 1930, V. 8, No. 8, p. 278-288.—A comprehensive treatment of pile driving calculations giving both theoretical analyses and experimental data for various soil conditions, types of hammer, and types of pile.—V. P. JENSEN

Experimental structural engineering. H. W. COULTAS. *Structural Engineer* (England), August, 1930, V. 8, No. 8, p. 290-301.—Theoretical discussion includes an historical review bringing out laws of general work and virtual work, Mohr's equations, and Maxwell's theorem of reciprocal deflections. Solution of indeterminate structures by means of models is described and Professor Begg's method and apparatus are discussed in detail.—V. P. JENSEN

Design of River Des Peres drainage channel, St. Louis, Mo. W. W. HORNER. *Eng. News Record*, July 24, 1930, V. 105, No. 4, p. 124-128.—Four of 13 miles of River des Peres Drainage Canal now under construction in St. Louis, Mo., will consist of reinforced concrete arch conduit. Of this

amount, 10,000 ft. will consist of twin arches each 29 ft. wide and remainder of single arches 32 ft. wide. In designing the arches, stress analyses were made for both completely fixed and completely hinged end conditions and the actual detailing was on the basis of stresses less than maximum in either case. Sections were designed for earth backfills of 5, 10, 15, and 20 ft. over the crown, and for three different bearing values under footings. Specified working stresses were 800 lb. per sq. in. for concrete and 20,000 lb. per sq. in for steel. Six sacks of cement were used for each cu. yd. with not more than 55 lb. of total water per sack of cement. Aggregates were varied to secure most workable concrete consistent with good practice. Materials were measured by weight and mixing time of 1½ minutes was required. Steel forms were specified and were required to remain in place until concrete had attained compressive strength of at least 1,200 lb. per sq. in. To determine this strength, cylinders were cast at time of pouring and cured under conditions similar to those of concrete in forms.—D. E. LARSON

Dock and harbor construction in British colonies. MAJOR JOHNSTONE-TAYLOR. *Concrete*, July, 1930, V. 37, No. 1, p. 23.—These notes are principally concerned with the use of reinforced concrete as an alternative to timber for jetty and bank protection work in a British Colonial development in Asiatic waters. On Whang Poo River, Shanghai, there are comprehensive works consisting of reinforced concrete skeleton wharf supported on piles of same material and reinforced concrete quay wall of buttressed class forming part of same works. Wharf is 174 ft. wide and 1160 ft. long. Piers are 15 in. square and spaced 15 ft. apart in each direction. Each pile in turn is supported on a group of 14 in. square piles. Beams run across the wharf from side to side over each row of piers and they support a system of cross beams spaced 5 ft. on centers. Bases of piers which are pile caps are connected both ways by horizontal members. Piles were molded in a horizontal position. Driving was effected without use of a steel helmet. A thin piece of pine was placed directly on the pile head, above which was a ¾ in. steel plate surmounted by 4 in. of hardwood. Arrangements were made for the pile to run in guides between rubber covered rollers packed with thin pine battens.—C. BACHMANN

Nomogram for calculating columns without spiral reinforcing (Axial load). JORGE QUIJANA. *Ingenieria* (Mexico), Feb., 1930, p. 57.—A simple alignment or nomographic chart, one of a series of such charts, for use in reinforced concrete design and investigation, solving the relation $P = [A_c + (n - 1)A_s] f_c$. Left hand scale or line A_c, middle scale P and right hand scale A_s. Explanation of the use is given on the chart. All in metric units.—MILES N. CLAIR and C. G. CLAIR

Nomogram for calculating columns reinforced longitudinally and with spiral reinforcing. JORGE QUIJANO *Ingenieria* (Mexico), Feb., 1930, p. 73.—A simple alignment or nomographic chart, one of a series of such charts for use in reinforced concrete design and investigation, solving the relation $P = A_c f_c + n f_c p A$. Left hand scale or line D or column diameter, middle scale P, and right hand scale p. Explanation of use is given on the chart. All in metric units.—MILES N. CLAIR and C. G. CLAIR

ARCHITECTURAL DESIGN

Modern church structures by Prof. Dominikus Boehm. A. HOFF. *Zement* (Germany), July, 1930, V. 19, No. 27, p. 640-1.—Several church constructions by one of the leading German architects are described. Modern church design differs very much from earlier methods. Vaults of great spans are desired which can be made of reinforced concrete. Arch construction without centerings were used by architect in building new church in Neu-

Ulm (Germany). Excellent acoustical and light effects were obtained in this structure. Similar designs were used in construction of churches in Gross-Welzheim and Frielingsdorf where special decorative window construction provides indirect light. Mass concrete is being used for convent in Muenchen-Gladbach. Finish of surface adds to strong effects. Concrete is more suited than any other material to produce architectonical effects in modern church construction.—A. E. BEITLICH

New Concrete filteration plant. FREDERICK COLEMAN. *Architect Building News* (England), May 9, 1930, V. 123, No. 3203, p. 35.—The new concrete filtration plant of Metropolitan Water Board at Kempton, England, is a splendid example of artistic possibilities provided by massing of concrete. This ferro-concrete building is a monolith: column and beam, arch and wall become *one* stone, in which connecting steel rods link the most distant parts together. The possibilities of texture, of color inhering in the product make it a thing through which the designer can make his feelings flow. The more a building tends toward a mono-material building, the more nearly will perfect style reward an organic plan and ease of execution economize results. The more logical will the whole become. In all real art, structure and design form an inseparable unity. . . . The problem is to express in beautiful forms the type of construction thrust upon us by a utilitarian age.—REXFORD NEWCOMB

Concrete. DR. ERICH MENDELSOHN. *Architect Building News*, (England), May 23, 1930, V. 113, No. 3205, p. 671-72.—The pliability of concrete leads many an architect to continue in his old habits with the new material, and not only as regards architectural style, but also in his building technique. But to build in concrete involves a revolution in building technique. We build frames—that is, we concentrate the load on single points instead of distributing it over the wall as a whole. We pour in concrete instead of, as formerly, setting the single parts, bricks or stones, on top of each other. We assemble a building like a machine; mechanical accuracy replaces the skill of craftsmen and his individual subtleties. For our buildings we require elevators and spouting towers instead of mason's guilds and scaffolding; we calculate exactly beforehand every detail of the construction; we organize on a large scale instead of being contented with empirical attempts and occasional lucky results. This fundamental alteration in the methods of building is one of the causes of change in ideas on architectural form. The success of the new material consequently give the architect entirely new creative possibilities. The second quality of the new materials, steel and concrete, that of being able to live a life of their own, to exist as absolutely independent materials, gives the lie to those architects who see in them only an additional means of realizing dreams born of their excursions into a mummified past. We rejoice in the new materials because they impose on us obligations which, if we accept, set us free for new and original creations. We know that constructions in steel and reinforced concrete are very difficult to alter. That is why we consider the plan of the building as though it were a living being. We carefully avoid anything in the nature of a schematic design, because each plan has its own life, its own purpose, its own conditions of movement and transport, its own unique form. We reckon with it and with its form as something determined by its nature—and thus harmonize calculation and form, industrial purpose and architectural form. We settle in advance the sequence of separate parts of the building; we determine its rhythm, which is of more value to us than any decorative trimmings. We see in constructing a creative activity; in the creative construction, an architectural work of art. With our girders we span the greatest spaces. We light them by great glass surfaces between the elastic supports. By means of glass we get rid of inert matter and make the building light and transparent. We transfer the principles of bridge construction to building and by means of cantilevers raise certain parts above the earth, and cause them to float in the air.—REXFORD NEWCOMB

Lincoln Cathedral repairs. *Architect Building News* (England), April 18, 1930, V. 113, No. 3200, p. 499.—The reparation of Lincoln Cathedral has so far proceeded that the interior of the nave is at last freed from scaffoldings. The reinforced concrete ties, holding in the west front which was in danger of falling outwards, have been completed; as also, similar reinforcements to prevent the future spreading of the arches under central tower, and the buckling of the nave walls.—REXFORD NEWCOMB

Concrete church Jacobi in Stettin (Germany). (See FIELD CONSTRUCTION—Buildings.)

FIELD CONSTRUCTION

BRIDGES

Bridge over river Allien in Langeac (France). FRITZ EMPERGER. *Zement* (Germany), June, 1930, V. 19, No. 23, p. 537-8.—From spring 1927 to spring 1929 this reinforced concrete highway bridge was built. River is 2 m. deep and 20 m. wide during greater part of year, but rises about 6 m. and is about 140 m. wide during high water periods. Total structure is 140 m. long and consists of two concrete arches carried on two shore abutments and one river pier. Bridge crosses river at approximate angle of 71 degrees. Span of each arch is 68 m. and their height is 13.6 m. Arch ribs are 0.60 m. wide and from 1.20 m. to 1.60 m. high. Roadway is 5.20 m. wide and has two sidewalks for pedestrians 1.10 m. wide on each side. Floor system shows normal design; it is suspended from the arches. Concrete floor slabs are covered with layer of asphalt. One centering was used for both arches since they have same dimensions. Difficulties were encountered in making foundations for river pier.—A. E. BEITLICH

Arrangement and preparation of structural materials for construction of bridge over river Ammer near Echelsbach (Germany). FERDINAND DUELL. *Die Bautechnik* (Germany), Jan., 1930, V. 8, No. 1 and 4, p. 9-15, 52-5.—Aggregates were found in 4 km. distance from site of construction. Gravel, which had high loam content was washed in special plant. Water was pumped 80 m. high from river with high pressure pump which delivered 8 cu. meter of water per hour through pipe (52 mm. in diameter) to tank of 10 cu. meter capacity. Sand was transported by truck to storage bins. Aerial tramway carried materials to opposite side of river. Two concrete mixers of 350 and 500 liter capacity were used. Cement silo had room for 25 carloads. Laboratory for testing cement and concrete was erected near site. Distribution and placing of concrete during all stages of construction are described. (cf. *Der Bauingenieur* (Germany), June 1930, V. 11, No. 23, p. 391-406.)—A. E. BEITLICH

Reinforcing of bridge over the river Roeder between Goerlitz and Dresden (Germany). FRITZSCHE. *Die Bautechnik* (Germany), Jan., 1930, V. 8, No. 2, p. 25-31.—Old railway bridge which was badly damaged by action of water and weather was widened and provided with new reinforced concrete supports. Interesting construction methods were used for connection of old and new structure. High early strength cement was used which gave compressive strength of 330 to 380 kg./cm.^{2} after three days.—A. E. BEITLICH

Bridge over river Breitach near Riezlern (Austria). E. MUELLER. *Die Bautechnik* (Germany), Jan., 1930, V. 8, No. 3, p. 33-5.—Highway bridge over deep valley of Breitach in Austrian Alps is three hinged arch bridge of reinforced concrete. Structure consists of three parallel arches of rectangular cross-section. Span is 51 m. and its height 13 m. Roadway is supported by

eleven vertical reinforced concrete frames, six of them resting on arches, rest being placed on special foundations on both shores. Openings between frames are 5.50 m. Arches are 1.10 m. high at abutments and 0.65 m. at centers; their width is 0.70 m. Cross-sections of columns vary from 30 by 30 to 40 by 40 cm. Roadway is 5.00 m. wide with two 1.00 m. wide sidewalks on both sides. Special construction of abutments was necessary. Detailed description of reinforcements is given. High early strength cement was used for greater part of structure. Compressive strength after 6 weeks was 250 kg./cm.^{2} Foundations were made from ordinary portland cement. Scaffolding and formwork consumed much labor since high water is very frequent. Two wooden towers, 15.6 and 16.9 m. high with pile foundation supported formwork for arches. Materials were mixed in one mixer on right shore. For one cu. meter aggregates 280 kg. portland cement was used. Dump cars transported concrete to big chute.—A. E. BEITLICH

Arch bridge near Echelsbach (Germany). H. SPANGENBERG. *Der Bauingenieur* (Germany), June, 1930, V. 11, No. 23, p. 391-406.—Highway bridge over river Ammer with span of 130 m., which is longest span bridge in Germany, was opened for traffic in December 1929 after one year of construction. Bridge makes short cut and eliminates long detour of important highway. System Melan-Sachsenberg was used for construction of two halves of arch which were built without centerings. Gravel load of weight of concrete was placed upon free ends of arches to keep stresses constant. Load was decreased in same rate as construction progressed. Bridge consists of two hollow box-shaped arches of 130 m. span, placed in 6 m. distance. Ten I-beams and two U-beams at abutments connect both arches. Ribs have constant width of 1.50 m., their height increases from 2.00 m. to 3.20 m. Walls of ribs are 35 cm. thick and are stiffened by inner partitions. Abutments are 11 m. wide. Roadway, which is 8.30 m. wide, rests on 14 vertical frames of different height supported by arches. Distance between frames is 10.50 m. Their dimensions increase with their length, greatest being 1.1 m. by 0.8 m. by 24 m. Two main girders of roadway are 1.10 m. high and 0.4 m. wide with distance of 6 m. Roadslabs are 20 cm. thick and are cross reinforced. Four expansion joints were made. Detailed description of steel structure is given. Special care was necessary for closing of arches in center of bridge. Author gives discussion of reasons why box-shaped cross section of arch ribs was selected. He also gives calculations of static and dynamic pressures and stresses which occur in structure. Forms were made at site in small sections and were raised to iron structure. Two suspended platforms could be moved along inner part of arches. Aggregates were found in neighborhood and furnished very good construction material after being washed. Mixture of 40 per cent sand and 60 per cent gravel of 25 mm. size with 340 kg. cement was used for one cu. meter of concrete. Compressive strength after 28 days was 390 kg./cm.^{2} Concreting was done without any difficulties. Concrete was transported in buckets for lower parts of arch and was poured through chutes in center part. Compressed air hammers provided dense concrete. For 14 days after pouring, concrete was wetted three times per day to prevent early shrinkage. Article is accompanied by 32 illustrations.—A. E. BEITLICH

The collapse of the bridge over the river Oder near Gartz (Germany). GUSTAV HAEGERMANN. *Zement* (Germany), May, 1930, V. 19, No. 21 and 22, p. 494-7, 517-21.—Bridge was three-hinged arch which rested on two pillars in river and two abutments on land. Entire structure was made of reinforced concrete. Distance between pillars was 58.2 m. and between pillars and abutments 37.7 m. each. Height of middle arch was 10.5 m.; side arches were 7.5 m. high. Width of street was 5 m. Collapse was caused by crumbling of one of pillars. Dimensions of pillars was 11.30 m. long and 3 m. wide. Construction was nearly finished and removal of wooden planks was started, when

pillar collapsed. Middle arch fell into river and broke. One of side arches was pushed 1 m. over abutment, breaking latter, but was not damaged. This proved the good quality of reinforced concrete. Samples of pillar were taken and some of them were very soft. Calculations of chemical analysis showed that approximately 20 per cent of cement had leaked out on account of heavy motion of water. Pillars were constructed by "under-water-casting" method with concrete of 1:6 mix. Heavy steel piles were driven 15.7 m. below water level and excavation was made 12.1 m. deep. Forms consisted of 1 in. planks with 0.5 cm. wide joints. Height was 8.8 m.; foundation was 13.20 m. long and 5.5 m. wide. Concrete mixer and distributing arrangement was placed on top of foundation. During pouring of concrete an excess of water forced its way into the excavation, which prevented part of concrete from hardening and caused separation of concrete components.—A. E. BEITLICH

Winter-laid 10,000-lb. concrete on Chicago viaduct. (See PROPERTIES OF CONCRETE).

BUILDINGS

How to save in concrete form work. A. B. MACMILLAN. *Concrete*, June, 1930, V. 36, No. 6, p. 38.—Principal feature in form work for drop panel around column head in flat-slab construction consists of square panel or platform that forms bottom of concrete drop panel. Form work for drop panel is supported in much same way as floor slab, namely, by a framework of joists and girts which in turn are supported by 3 x 4 in. or 4 x 4 in. centering posts. Two girts (one along each side of drop panel) furnish entire support for drop panel form. After panel is set in place its sides are closed with dressed 2-in. pieces whose dressed height is distance between bottom of finished concrete drop panel and finished floor slab, less ⅞ in. A ⅞-in. fillet is then tacked all around top of drop. Stripping of form work of the drop panel must be done in connection with stripping of rest of floor bay, as follows: (1) Assuming that "permanent" shores have been placed under surrounding floor bays and that metal forms of column capitals have been removed, loosen wedges between girts and tops of centering posts, but do not completely remove the wedges. (2) Remove two joists on one side of column by sliding them out of hangers, and let down that half of form panel. (3) Repeat foregoing operation on other side of column. (4) Remove double-headed nails from scabs. (5) Remove the 1 x 6 in. horizontal pieces that brace the centering posts, and take posts down.—C. BACHMANN

How to save in concrete form work. A. B. MACMILLAN. *Concrete*, July, 1930, V. 37, No. 1, p. 38.—Present article deals with form work for walls above grade. They may be ordinary exterior or interior bearing walls; or they may be curtain walls extending between pilasters, supported on their own footings but carrying nothing except their own weight; or they may be supported by pilasters and have no footings. Use of 30-in. wall form units employed in foundation wall construction is not usually advisable above grade. Better workmanship is obtained if form panels are built to size of entire wall panel, extending from pilaster to pilaster and from floor to floor. Inside panel extends from completed floor or other support to underside of form boards for floor above. Height of outside panel will depend on position of belt courses or similar details. Best type of waling strip consists of two 2 x 6 in. timbers spiked together through fillers of 1 x 6 in. material, about 3 ft. apart. Space should be found to build wall form panels for first story in a lying-down position alongside place where they are to be erected. Waling strips are laid down, vertical studs tacked to them with double-headed nails, and form boards are nailed to studs. Panels are then raised from both sides, joined with column or pilaster forms and tie bolts and concrete or wooden

spreaders placed and tightened. False frames for windows and other openings are set against outside panel before inside panel is raised. Form work for wall pilasters is erected independently in manner previously described. Pilaster form work should be erected and thoroughly braced before wall form panels are raised into position to provide secure anchorage for latter.—C. BACHMANN

New Herrentor high school in Emden (Germany). HIRT. *Zement* (Germany), July, 1930, V. 19, No. 31, p. 733-4.—Building covers area of 2940 m² and rests on foundation consisting of 1460 wooden piles 11 m. long. Floor construction in reinforced concrete is of interest. Arrangement of reinforcements is described.—A. E. BEITLICH

Construction of building corner in reinforced concrete. THOMAS. *Zement* (Germany), June, 1930, V. 19, No. 26, p. 616-7.—Corner of building which was hindrance for traffic in narrow street, was removed and upper stories of building supported by interesting reinforced concrete construction. —A. E. BEITLICH

Concrete church Jacobi in Stettin (Germany). K. DAHL. *Zement* (Germany), July, 1930, V. 19, No. 29, p. 681-2.—Formwork, placing of reinforcements, concreting and removing of forms for church construction was carried out within 9 weeks. Six concrete frames, spaced 5.0 m. apart, support structure. Inner ceiling is made of wood in order to improve acoustics.—A. E. BEITLICH

High school construction in Kassel (Germany). WILHELM DAVID. *Zement* (Germany), June, 1930, V. 19, No. 26, p. 610-3.—Difficulties were encountered in placing foundations. Ground consisted of loose filled material to a depth of 8 m. Numerous single foundations were made on which 4-story building rests. It is 25 m. long, 15 m. wide and 9 m. high. Roof is of reinforced concrete. Several side-buildings show interesting construction.—A. E. BEITLICH

Design and construction of modern factory in reinforced concrete. (See ENGINEERING DESIGN—Buildings.)

DAMS

Water power works at river Shannon in Ireland. M. ENZWEILER. *Die Bautechnik* (Germany), June, 1930, V. 8, No. 25, p. 359-70.—Shannon river is being dammed about 16 km. upstream of Limerick near village of O'Briensbridge. Water canal of 12 km. length with capacity of 600 cu. meters of water per second connects dam and power station. Difference in water levels of 30 m. is utilized in one stem for production of 90,000 kw. with three Francis-turbines of 38,600 H. P. each. Dam is of overflow principle and has two openings of 18 m. each with rigid crests. Four openings at base are 10 m. wide. Interesting feature of dam is construction of canal for passage of fish. It is made of concrete in 16 steps, each step being 50 cm. high, at left side of dam. Dam of intake canal is of similar design. It is founded on sandstone rock and has three openings of 25 m. and one 10 m. wide passageway for ships. Total structure is 97 m. wide between shore abutments. Upper part of openings is closed by one continuous gate which extends over all three openings with total length of 90 m. It is 5.40 m. high and 2.50 m. wide and consumed 620 cu. meters of reinforced concrete for its construction. Cross section of gate is box-shaped with two horizontal inner walls. Outer walls are 27 cm., bottom and floor are 40 cm. and inner walls are 28 cm. thick. Difficulties were encountered during construction of water canal, which leads to power station. Climatic conditions were very unfavorable with heavy rainfalls. During three and a half years of construction period a total of 7 million cu. meters of

ground and one million cu. meters of rock were moved. Three reinforced concrete bridges, two of them being three-hinged arch bridges, were built over canal. Power house rests on limestone rock and is entirely built of concrete. It consists of three sections, one of which is generating room for three turbine-driven generating units; other sections are for switchboards and transformers. Station is designed for later enlargement with total of 6 turbines. Water lock at end of water canal is of interesting design. Its foundations are placed on limestone rock. For construction of this 95.50 m. long structure were used 40,000 cu. meters of concrete. It is 27 m. high. Expansion joints were placed in 30 m. distance of each other; they are sealed with copper strips which are embedded in bitumen. Lock has six openings, three of which are connected with 6 m. wide pressure pipes. Centers of water pipes are spaced 15 m. apart. Special shaped concrete walls are placed in front of openings. Pipes between water lock and power house are 44 m. long each and are supported at three places. Opening of 5 m. is in water lock as passage for water when turbines are not in use. Article is completed by 38 illustrations and graphs, showing construction in all phases.—A. E. BEITLICH

Development of modern concrete fodder silos. H. HILDEBRANDT. *Zement* (Germany), July, 1930, V. 19, No. 30, p. 709-12.—Concrete fodder silo construction in Germany is described and advantages are discussed. Silos are air-and water-proof. Changes in temperature and internal pressure do not affect structures. Protective coatings make concrete acid resistant. Good heat insulating properties allow complete control of any fermentation process. Silage of excellent properties with high albumen contents can be prepared. Several photographs show different types of silos in use.—A. E. BEITLICH

MISCELLANEOUS

Reinforced concrete bins in the German bituminous coal region. STEINHEIT. *Zement* (Germany), July, 1930, V. 19, No. 27, p. 633-7.—Description of a number of coal bins under construction and completed structures. Reinforced concrete bin near Bitterfeld (Germany) with capacity of 8000 tons coal is 66 m. long, 13 m. wide and 26 m. high. Total of 13,200 cu. meters of ground were removed and 3000 cu. meters of concrete were consumed for this structure. Concrete was placed from distributing tower at rate of about 200 cu. meter per day. Compressive strength after 14 days was between 140 and 160 kg./cm.^{2} Coal distribution tables and conveyor belts are underneath bin. Foundation of coal bin near Meuselwitz consists of continuous concrete slab. Capacity is 1000 tons coal; building is 63 m. long and 7.40 m. wide. Several other structures are described.—A. E. BEITLICH

Ground construction. "Der Grundbau." L. BRENNECKE and ERICH LOHMEYER. 1930, 4th edition, Wilhelm Ernst und Sohn, Berlin, R. M. 25.00. Reviewed in *Zement* (Germany), July, 1930, V. 19, No. 28, p. 666.—Book deals with all construction methods for foundation jobs. Special consideration is given to reinforced concrete piles and breakwater construction. Second volume which is still in preparation will complete work on this subject. —A. E. BEITLICH

Concrete of any specified proportions produced by Rochester, N. Y., plant. *Pit and Quarry*, May 7, 1930, V. 20, No. 3, p. 76-78.—Describes ready-mix plant of Whitmore, Rauber & Vicinus, near center of city, which delivers to any job in city within 25 min. Firm has been handling aggregates for years. Aggregate portion of plant has capacity of 25 cars per day. Sand and gravel, received in bottom-dump railroad cars, are discharged into track hopper from

which belt feeder loads to inclined belt conveyors. These discharge the material through swivel chute to nine bins or to another belt conveyor which leads to mixing department. Cement is purchased in bulk and unloaded from box-cars by hand-scraper into hopper which feeds chain-bucket elevator. Cement is delivered to two of six bins above mixing department, each of 250-bbl. capacity. Sand and gravel leave bins through quadrant gates, cement through sliding gates. Weighing hopper is equipped with 3-beam scale having dial that registers only last 400 lb. Weighing hopper discharges to another hopper to await dumping into mixer at proper moment. Thus three batches are always in process simultaneously. Water is measured accurately by means of syphon arrangement. Mixer is of 2½-cu. yd. capacity and prepares an average of 350 cu. yd. in 9-hr. day, although it has prepared 400 cu. yd. Mixer is driven by 40 H. P. motor. One man controls mixing department. Concrete is delivered in trucks with bath-tub bodies. Four illustrations.—A. J. HOSKIN

Placing concrete by compressed air. C. H. MUNRO. *Australasian Engineer*, June 7, 1930, V. 30, No. 168, p. 5.—One of earliest pneumatic placers worked on the following principle, and modern methods are but improvements on it: A mass of concrete is placed in a chamber with restricted outlet, and uniform air pressure applied towards the outlet. When, and not until, a further jet of air is blown into the mass near outlet, a small portion, or submass becomes detached and forced into delivery pipe. As each submass is forced into the pipe, the pressure falls and pressure behind mass forces more up to outlet. Process is thus repeated continuously. In later refinements rise in pressure behind the main mass due to cartridge effect of the construction, operates a piston valve in secondary jet line when it reaches a given pressure, adjusted by springs. In practice both valves open almost simultaneously. Various works, mostly tunnels, on which this method of placing concrete has been successfully employed are described. Generally the guns do their own mixing.—JOHN E. ADAMS

Vibrated concrete. E. TREVES. *Le Genie Civil*, (France) June 28, 1930, No. 2498, p. 636.—Vibrated concrete was first tested by Freyssinet in 1917. Making use of compressed air he has since successfully used this method on large scale reinforced concrete construction. Surface vibration was patented in France by M. Berenguier and was commercialized by the society "La Route" since 1927. The vibration of the mass was first introducted by Deniau and has since 1928 been commercially exploited by the Societe des Procedes Techniques de Construction. Advantages of vibration are: perfect homogeniety of concrete, even for dry consistencies; partial elimination of air and water; constant quality concrete permitting a reduction of factor of safety; early removal of forms; good agreement of compressive strengths and their increase from 30 to 200 per cent; constant flexural strength, 16 per cent greater than that of surface vibration only; increased density (1 cu. m. of concrete requires tamping 1200 liters of material; vibration requires 1300 to 1400 liters and pervibration (vibration of the mass) requires 1450 liters. The volume of voids is reduced by one half. The rising of laitance, due to vibration secures a smooth surface. Porosity is reduced and thus danger of infiltration and corrosion by noxious agents. Vibrated concrete is easily adaptable to decorative effects.—M. A. CORBIN

Concrete and reinforced concrete construction. "Fertigkonstruktionen im Beton- und Eisenbetonbau." A. KLEINLOGEL. 1929, Wilhelm Ernst und Sohn, Berlin, 91 pp. R. M. 8.60. Reviewed in *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereins* (Austria), May, 1930, V. 82, No. 21-22, p. 187.—Advantages are described of structural parts of concrete and reinforced concrete which are made in shop ready to put together on job. No forms are necessary and construction can be carried out at much greater

speed. It can be applied to different types of floor construction, large halls, vaults, bridges, breakwaters and railroad structures.—A. E. BEITLICH

Blame divided for Detroit sewer failure. *Eng. News Record*, Aug. 7, 1930, V. 105, No. 6, p. 210-211.—Insufficient soil investigation, inadequate design, inspection and supervision, together with faulty construction, were held by investigating committee to be contributing causes to failure of Detroit sewer. Responsibility was placed jointly on department of public works and contractor. Failure was caused directly by removal of foundation composed of fine water-bearing sand which was carried into the interior of the barrel by groundwater through faulty concrete construction joints and openings developing in barrel after construction. Physical inspection of concrete showed proper proportioning but faulty workmanship in placing, resulting in porous low-strength concrete and thin walls. Thickness of sewer walls was found to vary from 6¾ in. to 26 in. Specifications required minimum thickness of 16 in. Tests of cylinders cored from sewer barrel showed compressive strengths varying from 987 to 6,171 lb. per sq. in. Samples of concrete analyzed in the laboratory showed proportions ranging from 1:2.6:1.8 to 1:3.4:5.3. Although these tests showed evidence of too much sand in the concrete, it might have been due to finely divided quicksand being carried into concrete by infiltering ground water and is not necessarily proof of an oversanded original mix.—D. E. LARSON

Foundations of gas engine plant in Hamborn (Germany). *Zement* (Germany), June, 1930, V. 19, No. 23, p. 541-3.—Foundations for power house with four gas engines is described. Engines are driven with blast furnace gas and furnish compressed air for blast furnaces. Strong vibrations of explosions require special foundation construction. Detailed description of reinforcement is given. Total of 10,500 cu. meters of concrete with 1350 tons of steel were used for foundations; approximately 130 kg. steel were placed in one cu. meter concrete. Water cooling plant and other minor structures consumed 5000 cu. meters concrete.—A. E. BEITLICH

Modern elevator for construction materials. *Zement* (Germany), June, 1930, V. 19, No. 25, p. 595-6.—New type of elevator for rapid transportation of structural materials is described. Highest permissible load is 600 kg. Elevator is easy to install and to move. No scaffolds are necessary.—A. E. BEITLICH

Concrete and reinforced concrete in electro power station construction. BREITUNG. *Zement* (Germany) June, 1930, V. 19, No. 25-26, p. 586-91, 613-6.—Article describes numerous possibilities for application of concrete and reinforced concrete in construction of water and steam power plants for production of electrical energy. Concrete is favorable material for dams and hydraulic structures since good combinations of cements and aggregates guarantee high strength and impermeability. Pressure pipes and intakes can be made of reinforced concrete. Foundations for water and steam turbines can be designed to reduce vibrations to minimum. In generating plants which use steam, concrete is used for construction of coal bins, water tanks, steam condensers and cooling towers. Large field for use of concrete is construction of stacks and poles. Nineteen photographs and drawings are reproduced.—A. E. BEITLICH

Under-water-casting of concrete. W. NAKONZ. *Die Bautechnik* (Germany), Jan., 1930, V. 8, No. 3, p. 35-6.—Methods of casting concrete foundations under water are described. Directions are given for correct working of concrete. Casting must be carried out without any interruption. Funnel must be always filled and movable in all directions. Excavation must be pro-

tected from running water which might cause excessive loss of cement. Difficulties increase with increasing depth of foundation. More than one funnel has to be used when large foundations are placed. Concrete should be earth-moist in order to prevent too rapid flow of mixture. All advantages of different methods and several possibilities for their application are described. —A. E. BEITLICH

Ready-mixed concrete plant for small city. *Concrete*, July, 1930, V. 37, No. 1, p. 27.—Ready-mixed concrete requirements of small city are well covered by small plant of W. A. Gingrich, in South State Street, Ann Arbor, Mich. Sand and gravel are brought, in proper proportions, from commercial pit three miles away. Only material stored at plant is cement. One man employed brings mixed sand and gravel from pit, dumps it into skip of mixer, brings cement from warehouse, charges mixer and sets it into operation, then drives truck around to other side of mixer, dumps concrete and delivers it. Mixing proportions, as a rule, are 1:2:4, but customers are supplied with any proportions desired. A water-control device regulates quantity of mixing water and maintains uniformity from batch to batch. Price for this mixture is $6.50 per cu. yd., delivered.—C. BACHMANN

Chemical technology for contractors. "Chemische Technologie fuer Bauingenieure." DR. FRANZ HEMMELMAYER. 1930, Ferdinand Enke, Stuttgart (Germany). 123 pp., 27 illustrations. R. M. 8.50. Reviewed in *Zement* (Germany), June, 1930, V. 19, No. 23, p. 548.—Book is one volume in Enke's "Collection for Chemistry and Technology." It describes all chemical reactions and materials which are of interest to the contractor. Four parts deal with following subjects: Water and water purification, illumination, explosives and structural materials.—A. E. BEITLICH

New forms and simple apparatus to determine the water permeability of concrete. ERNST RISSEL. *Zement* (Germany), June, 1930, V. 19, No. 23, p. 532-5.—Old methods of determining water permeability of concrete show several disadvantages. Cross-section through which water penetrates cannot be exactly determined. Direction which is studied is mostly vertical to actual direction of water penetration in practice. New forms are described, which allow examination of both directions. Concrete joints are also taken into consideration. Sawing of concrete test cylinders is not necessary and forms can be made with very little costs. Exact dimensions and directions for the preparation of the test pieces are given. Pressure is kept constant by 13 m. high water column. Five test pieces can be connected to this water line. Temperature in room is kept between 15° and 20° C.—A. E. BEITLICH

Reinforced concrete storage silo for malt. F. KOENIG. *Zement* (Germany), July, 1930, V. 19, No. 31, p. 735-6.—Silo which consists of 16 separate compartments has capacity of 4900 cu. meters. Underground was very soft and structure was placed on strongly reinforced Pilz-slab. Twenty-five concrete columns distribute load on foundation. Walls were constructed with sliding forms; they are 17.10 m. high and 15 cm. thick. One cu. meter concrete was made with 310 kg. cement. Cube tests showed 200 kg./cm.^{2} strength after 28 days.—A. E. BEITLICH

Use and abuse of building materials. A. M. GILES. *Builder* (England) June 20 and June 27, 1930, V. 138, Nos. 4559 and 4560, p. 1192 and 1235.—Concrete: It is essential that dry ingredients be well mixed before water is added or voids will not be filled, and sufficient water must be added to cause complete hydration. River water is generally satisfactory if uncontaminated by factory refuse. Sea water may sometimes be used where setting time and appearance are not important. Contaminated water should not be used unless 28-day compression tests give results not less than 80 per cent of clean

water values. It is suggested that correct amount of water may be taken as 28 per cent of weight of cement plus 4 per cent of weight of combined aggregates in mix. The slump test is given in detail, and its frequent application recommended. In experiments with 1:2:4 mix, 17 per cent shrinkage in volume was observed after mixing dry. Final decrease after 28 days, was 27 per cent volume of dry materials. Methods of hand and machine mixing are discussed. For machine mixing, dry materials should be mixed 15-20 secs. Tests show that 5 min. mixing gave 3200 lb. per sq. in. concrete in 28 days, and 1 min. mixing 2900 lb. per sq. in. Many faults are due to insufficient curing. Concrete should be kept damp for two or three weeks. Forms left in place as long as possible retard evaporation. Setting time is determined by flow table. All concretes are more or less permeable, and circumstances affecting this property are many. Clean sand and correct amount of water are main essentials.—JOHN E. ADAMS

ROADS AND PAVEMENTS

Steel forms for road work. *Indian Concrete J.* (India), June 15, 1930, V. 4, No. 6, p. 172.—A new type of steel form is illustrated, which may be used for any thickness of slab between $3\frac{1}{8}$ in. and 9 in. It consists of two steel channels of different sections and a central steel flat. The latter is $1\frac{1}{2}$ in. narrower than the space between the channels and is connected to the support by a countersunk bolt and nut moving in a slot. This arrangement permits vertical movement and leaves spaces through which the reinforcement may pass. No fixing or pegging down of forms is required and there are no loose parts. The method is also applicable to curbing.—JOHN E. ADAMS

Examples of road construction in Vauclose. *Australasian Engineer*, June 7, 1930, V. 30, No. 168, p. 4.)—Road construction in Vauclose is mainly confined to the concrete and bituminous macadam penetration types. The latter is more favored since reasonable serviceable roads are preferred to those with no maintenance costs, but higher first costs. A macadam surface, practically free from waviness has been obtained by handpacking foundations in squares, to a depth of 9 in., the grain of the stone being laid across the road to avoid splitting. For concrete roads longitudinal screeding is recommended because despite the greater number of joints the grain of the surface runs with the traffic.—JOHN E. ADAMS

SHOP MANUFACTURE

Concrete products industry needs more substantial equipment. *Concrete*, August, 1930, V. 37, No. 2, p. 41.—There is little question that the products industry is due for a rather thorough overhauling in matter of equipment, even though several years may elapse before the process is completed. The industry has come a long distance since the day when concrete block machines exhibited at annual cement shows consisted of light-framed contraptions operated by a foot pedal. Now industry is installing heavier and sturdier equipment, fully automatic in its operation. Advantages of this modern equipment are many. It is labor-saving; it places a plant on a large production basis, for a single machine capable of producing six or eight units of standard size in a minute will have a capacity of 3,600 or 4,800 units in 10 hours of actual operation.—C. BACHMANN

Preparing concrete masonry advertising. T. A. DAY. *Concrete*, July, 1930, V. 37, No. 1, p. 35.—Probably best medium for local manufacturer is the newspaper reaching prospective home owners in his community, if he intends to spend his advertising money in residential field. Choose the newspaper that will carry the message to the greatest number of prospects. It is

generally agreed that manufacturer can make no better investment in his merchandising program than to tie in his newspaper advertising with educational copy provided by Architects' Small House Service Bureau. By placing his advertisement in issues in which concrete masonry house is described, he obtains three or four times the advertising space devoted to concrete masonry that he would ordinarily obtain. Success in advertising depends greatly upon ability of advertiser to make reader remember him and his product. Advertisers rely upon repetition of outstanding points to help them obtain new acquaintances and additional users.—C. BACHMANN

Successful piece-work pay system in concrete products plant. R. J. FISHER. *Concrete*, June, 1930, V. 36, No. 6, p. 16.—In general, there are three piece-work payment plans. One consists of paying foreman for all labor. Second system consists of definite apportioning of pay for labor among all men. Third system consists of paying mixer operator, machine operator and off-bearers on piece work basis and hiring day labor for curing room and stock piles. The Economy Concrete Products Co., Milwaukee, Wis., has adopted system under third classification. Prices for each unit of work were determined and set of rules and regulations adopted. These were presented to employees in a letter. Under old system, production per man per 10-hr. day for 8, 10, and 12 in. units averaged about 750, 725 and 500 units respectively. New system averages about 1100, 1050, and 675, respectively. This increase was brought about by using two men to the machine instead of usual three. Production for each machine is but slightly less, from about 2½ per cent for the 8 in. unit to about 10 per cent for the 12 in. unit. The price of 60 to 95 cents a hundred for units from the 4 in. to the 12 in. size is enough incentive to bring production close to the maximum. System is too new to get a detailed report on costs, but taking the average of the 6, 8, 10 and 12 in. units, the cost has been reduced by 0.4 cents per block. It was formerly 2 cents. Under old system it was not uncommon for production to drop 20 to 25 per cent below average daily production, causing wide variation in the cost per unit. Under the new system, labor cost per unit remains the same. Saving is also made in unloading cement. Price of ¾ cents per bag looks low, but has netted men an average of 83 cents an hour. A thousand-bag car is unloaded by nine men in less than an hour.—C. BACHMANN

Well-designed, attractive products plant is credit to industry. *Concrete*, July, 1930, V. 37, No. 1, p. 20.—Cement Products Co., Davenport, Iowa, has a large volume of business in its cast stone work. This means that among the visitors to the plant are people of influence. In their visits they are often investigating merits of material made at this plant as compared with natural stone, or with cast stone made elsewhere. Plant has real business office, located on second floor of building. Principal office space is divided into front office and two private offices. Farther on is the office of the sales manager, while at the far end in the corner of the building, is the office of the president. Building is 2-story structure, built of high-grade concrete units. The structure is 138 ft. by 51 ft. The offices and drafting rooms on second floor occupy a strip about 14 ft. wide. Manufacturing space is rather symmetrical in plan, about 138 ft. long and 38 ft. wide. Each end of the manufacturing space is occupied on ground level by curing kilns, four in each end, and each kiln is equipped with two tracks. Above curing kilns is reinforced concrete floor slab which provides a floor space of about 34 by 40 ft. at each end of the building, these two floor areas being joined by a balcony floor.—C. BACHMANN